Agri-cultural Chemistry

## 2

Edited by B. A. YAGODIN

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Volume 2 of the textbook covers individual inorganic and organic fertilizers, their composition, properties, rational application techniques, as well as the physiological role of individual nutrient in plant development.

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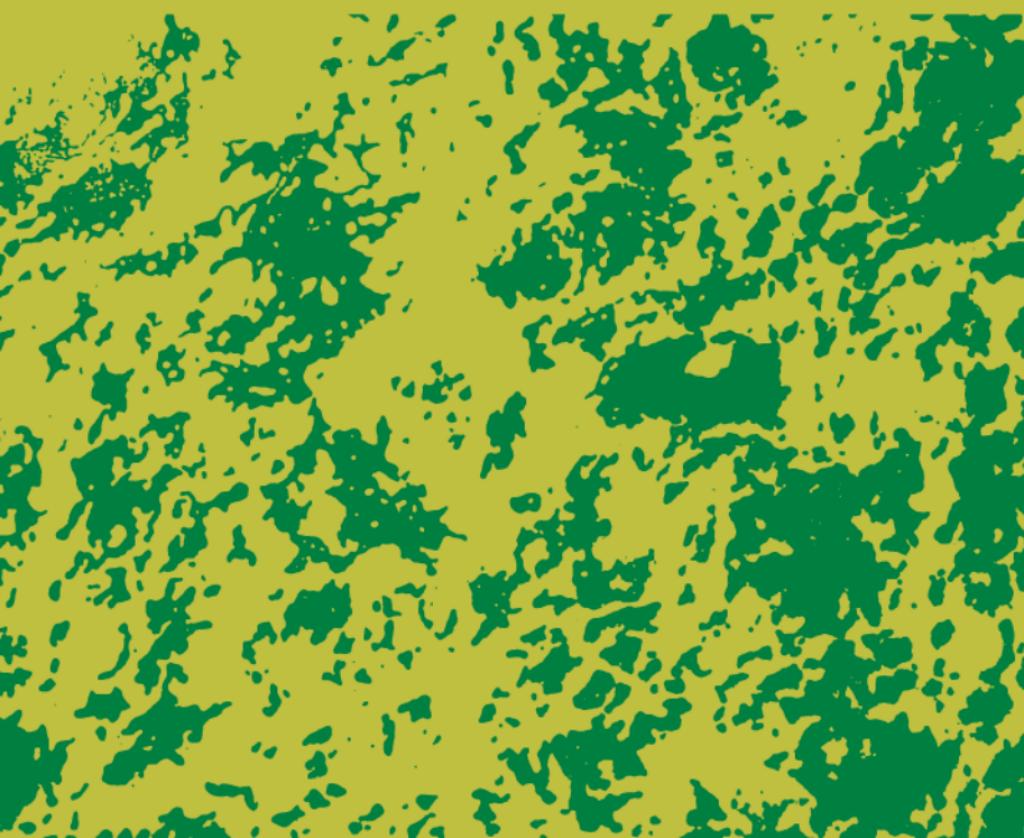
Agri-
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Агрохимия
Часть II

под редакцией Б. А. Ягодина

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Edited by B.A.YAGODIN, D.Sc.

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Micronutrient Fertilizers

1.1 Importance of Micronutrients

Micronutrients are present in plants in amounts ranging from thousandths to hundred thousandths of a per cent and perform essential function in vital processes.

The theoretical aspects of micronutrient application in agriculture became better known after the physiological role of micronutrients in the life of plants had been partially revealed. A major contribution to elucidating the theoretical and practical aspects of micronutrition of plants must be credited to Peive, Katalymov, Vlasyuk, Kedrov-Zikhman, and other scientists.

A lack of micronutrients is responsible for some plant diseases and often causes crops to perish. Application of appropriate micronutrients not only prevents these diseases, but also ensures higher yields of better quality crops.

The beneficial effect of micronutrients stems from their involvement in redox processes, carbohydrate and nitrogen metabolisms, as well as their enhancing the resistance of plants to diseases and adverse environmental conditions. Micronutrients increase the chlorophyll content in leaves, improve photosynthesis, and intensify the assimilating activity of the whole plant. Many micronutrients are constituent parts of the active centres of enzymes and vitamins.

The theoretical and practical studies into micronutrients currently under way are characterized by the investigators' desire to elucidate the primary reactions involving micronutrients and to gain a better insight into the specificity of their action and the associated physiological behaviour. A lot of work is being done to bring to light the agronomical role of micronutrients.

An important problem of theoretical and practical significance from the standpoint of micronutrient application is the requirements of various crops for them. For example, legumes contain much more molybdenum and accumulate

Table 1.1. Micronutrient Content in Plants (mg/kg dw)

Plant	B	Mo	Mn	Cu	Zn	Co
Winter wheat: grain	—	0.20-0.55	12-78	3.7-10.2	8.7-35.5	0.06-0.10
Spring wheat: grain	2	0.25-0.50	11-120	4-130	11.4-75	0.05-0.13
straw	2-4	—	60-146	1.5-3	10-50	—
Rye: grain	—	0.20-0.54	8-94	3.4-18.3	9.8-35.8	0.05-0.21
Barley: grain	2	0.39-0.46	8-140	3.9-14.3	9.6-50	0.05-0.11
straw	3-4	—	37-90	3.8-6.6	10-55	—
Oat: grain	2-3	0.28-0.74	10-120	4-13.9	8.4-50	0.02-0.14
straw	—	0.74	63-153	3.7-7.5	5-30	—
Pea: seeds	—	0.70-8.40	7-25	5.2-23.3	14.1-56.1	0.12-0.35
Common vetch: seeds	—	1.20-2.51	11-26	5.4-12.2	12.7-48.9	0.17-0.44
Timothy	4	0.40-0.81	11-135	5.8-26.3	10.2-40.1	0.05-0.28
Clover	12-40	0.28-3.50	10-278	4.5-20.8	14.0-180	0.13-0.42
Maize: forage	1-2	0.20-0.80	21-197	3.0-11.5	5-36	0.07-0.40
Alfalfa: hay	68	—	13-86	6.2-20.3	11-37	0.20-0.85
Sugar beet: roots	12-17	0.10-0.20	50-190	5-7	15-84	0.05-0.29
tops	20-35	0.40-0.60	128-325	6.9-8.4	14.7-124	0.25-0.50
Potato: tubers	6	—	8-21	4.7-6	6-20	0.14-0.69
Fodder cabbage	5-20	—	25-135	3.5-6.9	5-35	0.04-0.20

two to ten times as much iron as cereals, while at the same time they require more cobalt than other crops do (Table 1.1).

One of the criteria of adequate supply of micronutrients to crops is their content in the soil with emphasis shifting from the overall content of individual micronutrients to the presence of mobile forms, which to some extent determine their availability to plants. In the case of Cu, Mo, Co, and Zn, the mobile forms account for 10 to 15 per cent of their overall content in the soil, the percentage of mobile boron varying from two to four.

If the overall reserves of micronutrients in the soil are primarily determined by their content in the parent rocks, the content of their mobile forms depends on the soil type, nature of parent rocks and vegetation, and also the microbiological activity of the soil. The redox and other properties of the soil have been found to influence considerably the mobility of micronutrients and hence their availability. The effect of certain soil conditions is rather specific for different micronutrients. For instance, if acidification markedly increases the mobility of most micronutrients (Mn, Cu, B, Zn, etc.), the availability of molybdenum is minimized.

The term "mobility" is yet to receive a clear-cut definition in scientific literature. Most investigators use this term to imply all forms and amounts of micronutrients passing into any extract, be it a water or a salt one, dilute strong mineral and weak organic acids, alkalis, or any other solutions, with no distinction being made in most cases between the mobile and available forms.

Agrochemical investigations of soils in the Soviet Union have shown that the soils of some biogeochemical provinces are often deficient in mobile forms of certain micronutrients. The lack of gradation of micronutrient contents in the soils and crops under investigation has been prompting research workers and practising agronomers to use whatever standard reference is at hand.

Yagodin and Vernichenko have summarized the data concerning the presence of mobile micronutrient forms in the major biogeochemical zones of the Soviet Union, established during soil and crop analyses and as a result of field and greenhouse experiments (Table 1.2). As can be

Table 1.2. Mobile Micronutrient Contents in Soils in the Soviet Union

Micronutrient	Biogeochemical zone	Soil extract	Micronutrient content (mg/kg of soil)				
			very low	low	medium	high	very high
B	Taiga and forest	H_2O	0.2	0.2-0.4	0.4-0.7	0.7-1.1	1.1
Cu		1.0 N HCl	0.9	0.9-2.1	2.1-4.0	4.0-6.6	6.6
Mo		oxalate	0.08	0.08-0.14	0.14-0.30	0.30-0.46	0.46
Mn		0.1 N H_2SO_4	1.0	1.0-25	25-60	60-100	100
Co		1.0 N HNO_3	0.4	0.4-1.0	1.0-2.3	2.3-5.0	5.0
Zn		1.0 N KCl	0.2	0.2-0.8	0.8-2.0	2.0-4.0	4.0
B	Forest-steppe and steppe	H_2O	0.2	0.2-0.4	0.4-0.8	0.8-1.2	1.2
Cu		1.0 N HCl	1.4	1.4-3.0	3.0-4.4	4.4-5.6	5.6
Mo		oxalate	0.10	0.10-0.23	0.23-0.38	0.38-0.55	0.55
Mn		0.1 N H_2SO_4	25	25-55	55-90	90-170	170
Co		1.0 N HNO_3	1.0	1.0-1.8	1.8-2.9	2.9-3.6	3.6
Zn		ammonium acetate	4.0	4.0-6.0	6.0-8.8	8.8	—
B	Arid steppe and semi-steppe	1.0 N KNO_3	0.4	0.4-1.2	1.2-1.7	1.7-4.5	4.5
Cu		HNO_3 (according to Gyulakhmedov)	1.0	1.0-1.8	1.8-3.0	3.0-6.0	6.0
Mo		ditto	0.05	0.05-0.15	0.15-0.5	0.5-1.2	1.2
Mn		ditto	6.6	6.6-12.0	12-30	30-90	90
Co		ditto	0.6	0.6-1.3	1.3-2.4	2.4	—
Zn		ditto	0.3	0.3-1.3	1.3-4.0	4.0-16.4	16.4

seen from the table, the range of extracts used is extreme-
ly wide, from strong acids to aqueous solutions. Most of
them are rather aggressive and tend to extract a lot more
than merely available micronutrients. When the amounts of
micronutrients taken up by plants were compared with those
passing from the soil into aggressive extracts, it was found
that plants take up less than one per cent of the micronu-
trients extracted from the soil.

It should also be pointed out that a certain degree of
caution must be exercised in estimating the available
micronutrient contents in soils and giving practical recom-
mendations because of the evidence to the effect that the
content of mobile micronutrient fractions changes substan-
tially depending on the sampling date. These changes may
sometimes be so pronounced that at different points in time
during the vegetation period a soil may have high and low
contents of available micronutrient compounds.

Moreover, to correctly assess the micronutrient supply to
plants, one cannot disregard such complex dynamic phenom-
ena as synergism and antagonism involving micronutrients.
This might suggest that, apart from analysis of soils for
mobile micronutrient content, a better insight into the
supply of micronutrients to crops can be provided by the
crops themselves.

Boron was discovered in the ash of plants in mid 19th
century. This element occurs widely in nature in the form
of oxygen compounds of boron-containing minerals, such
as boric acid, H_3BO_3, and borax, $Na_2B_4O_7 \cdot 10H_2O$.

The average boron content in plants is 0.0001 per cent,
or 0.1 mg/kg fw. The boron requirements are the highest in
dicotyledons. High concentrations of boron have been found
in flowers, especially stigmata and styles. Most of boron
in plant cells is localized in cell walls. Boron speeds up
the growth of pollen tubes, activates the germination of
pollen, and increases the number of flowers and fruits. Seeds
fail to mature without boron. It lowers the activity of oxi-
dizing enzymes and influences the synthesis and migration of
growth stimulators.

Plants need boron throughout their lifetime. It cannot be
reutilized in plants, which is why its deficiency first of all
adversely affects young, growing organs. The first indications

of boron deficiency include diseased and dying growing points.

Boron in plants promotes carbohydrate metabolism and influences the protein and nucleic acid ones. Boron deficiency upsets the synthesis, transformations, and migration of carbohydrates, formation of reproductive organs, fertilization, and fruit bearing.

According to Shkolnik, the following physiological processes are upset in dicotyledons when boron is deficient. First, phenols are accumulated, then the phenolic inhibitors of auxinoxidase lead to accumulation of auxins, which upsets the nucleic acid metabolism and biosynthesis of protein. This is followed by deterioration of the cell wall structure and upset division of cells. As a result, tissues turn brown after the vacuolar tonoplast becomes more permeable under the effect of phenols, and polyphenols penetrate the cytoplasm. The main physiological function of boron is believed to be its involvement in the exchange of auxins and phenolic compounds or, more specifically, regulation of auxin and phenol contents. Boron is not a constituent of enzymes, yet it activates auxinoxidase and β-glucosidase.

When boron is deficient, plants are afflicted with dry rot (root crops), yellowing (alfalfa), brown rot (cauliflower), dry top rot (tobacco), hollowness (turnip and rutabaga), bacteriosis; flax also suffers from upset fertilization, and in sunflower the growing point dies away.

Crops particularly sensitive to boron deficiency include sunflower, alfalfa, fodder root crops, flax, rice, fodder cabbage, vegetables, and sugar beet.

High boron contents cause toxicosis, in which case boron tends to accumulate primarily in leaves. Excess boron inflicts what looks like burns on lower leaves, whereby they turn yellow, undergo edge necrosis, die, and fall off.

Various farm crops respond differently to high boron content in the soil. For example, grain crops may suffer from boron excess already when the content of its mobile forms is 0.7 to 8.8 mg/kg of soil, while alfalfa and beet tolerate as much as 25 mg/kg and more of boron in the soil. Mobile boron contents above 30 mg/kg of soil cause serious diseases not only in plants but also animals.

The boron toxicity threshold is determined not only by

its content but also by its quantity and ratio to other nu-
trients. When plants are adequately supplied with calcium
and phosphorus, their boron requirements increase.

The role of boron is especially important in liming of acid
podsolic soils because liming reduces the availability of
this nutrient, fixes it in the soil, and slows down its uptake
by plants. Application of boron to limed soils completely
rules out the possibility of root crops being afflicted with
heart rot and potatoes with scab.

Responding favourably to boron fertilizers are clover,
alfalfa, potato, buckwheat, maize, pulses, grape, apple,
and other crops.

Little boron is found in soddy podsolic, soddy gley, and
waterlogged soils of light texture. In tundra soils, the overall
boron content ranges from 1 to 2 mg/kg and that of mobile
boron may reach 0.1 mg/kg, while in soddy podsolic soils
these contents are 2 to 5 and 0.04 to 0.6 mg/kg, respectively.

Boron application is worthwhile if the content of its
mobile forms is less than 0.2-0.5 mg/kg in soils of the Non-
Black Earth zone, 0.3-0.65 mg/kg in the chernozem belt,
and 0.45-2.0 mg/kg in the sierozems and chestnut soils of
Central Asia.

Application of boron to soils deficient in this micronu-
trient increases the yield of flax straw by 2 to 3 centners per
hectare and that of sugar beet by an average of 45 centners
per hectare with a 0.3-2.1% increase in the sugar content
(Table 1.3).

Table 1.3. Effectiveness of Boron Fertilizers on Soddy Podsolic Soils

Crop	Number of runs	Average yield (cent/ha)	Yield increase due to boron (cent/ha)
Sugar beet	53	246	38
Sugar beet (on peat-boggy soils)	10	376	37
Flax (seeds)	20	5.6	1.2
Potato	8	216	40
Carrot	10	334	56
Cabbage	10	492	124
Tomato	18	557	51

The most widely used boron fertilizers in agriculture are boronated superphosphate and boracic-magnesium fertilizer (Table 1.4).

Table 1.4. Boron fertilizers

Fertilizer	Percentage of water-soluble boron
Commercial boric acid	17.3
Boron powder	2.4–2.8
Boracic-magnesium fertilizer	2.27
Pelletized boronated superphosphate	0.2 ± 0.05

The boronated superphosphate supplied to farms is used primarily in areas of beet and flax cultivation.

Boronated superphosphate containing 0.2% B is applied to sugar beet, root crops, pulses, and buckwheat. The rate of its basal application is 2 to 3 centners per hectare, while its drilling rate is 1 to 1.5 centners per hectare. Flax is treated at a basal application rate of 1.5 centners per hectare and at a drilling rate of 0.5 centners. Boracic-magnesium fertilizers (2.2% B) are used to treat sugar beet, fodder root crops, pulses, buckwheat, and flax; they are applied mixed with other fertilizers at a rate of 20 kg/ha.

Table 1.5. Application of Boron Fertilizers

Fertilizer	Crop	Rate (per ha)	Application
Boronated superphosphate (0.2% B)	Sugar beet, fodder root crops, pulses, buckwheat	2–3 cent 1–1.5 cent	Basal Drilling at seeding
	Flax	1–5 cent 0.5 cent	Basal Drilling at seeding
Boric acid (17% B)	Perennial grass and vegetable seeds	500–600 g	Pre-plant. Foliar dressing (100 g per centner of seeds)
Boracic-magnesium fertilizer (2.2% B)	Sugar beet, fodder root crops, pulses, buckwheat, flax	20 kg	Mixed with other fertilizers

Boric acid (17 % B) is used for foliar dressing at rates rang-
ing from 500 to 600 g/ha to treat perennial grass and vegeta-
ble seeds, as well as for pre-plant treatment of seeds of various
crops at a rate of 100 g of boric acid per centner of seeds
(Table 1.5).

Copper. The average content of copper in plants is 0.0002
per cent, or 0.2 mg/kg fw, and depends on crop species
and soil conditions. Various crops remove 7 to 327 g of
copper per hectare when harvested (Table 1.6).

Table 1.6. Copper Content in Crops Grown on Soddy Podsolic Soils
and Deep Chernozem (according to Katalymov)

Crop	Soddy podsolic soils		Deep chernozem	
	yield (cent/ha)	Cu content (mg/kg)	yield (cent/ha)	Cu content (mg/kg)
Spring wheat:				
grain	23	7.7	10	5.2
straw	24	3.0	14	1.5
Oat:				
grain	22	5.8	20	3.6
straw	39	7.5	21	3.7
Spring vetch:				
hay	40	12.2	25	4.7
Potato:				
tubers	270	6.0	—	—
haulm	500	18.0	—	—
Sugar beet:				
roots	542	6.4	280	6.5
tops	450	8.4	100	6.9

Two thirds of copper in a plant cell may be in an insoluble
combined state. The copper content is relatively high in
seeds and the most viable, growing parts of plants. 70 per
cent of all copper present in leaves are localized in chloro-
plasts. The physiological role of copper is largely deter-
mined by its being incorporated in copper-containing proteins
and enzymes catalyzing the oxidation of diphenols and
hydroxylation of monophenols, such as orthodiphenol oxi-
dase, polyphenol oxidase, and tyrosinase.

Known best of all is the copper-containing enzyme cy-
tochrome oxidase. It is believed that its copper and iron
are localized in a single active centre of the enzyme.

The copper-containing protein plastocyanin performs es-
sential functions in plants. Almost half the entire copper
in the leaves of some plants is in the form of plastocyanin.

Copper deficiency in plants sharply decreases the activity
of copper-containing enzymes.

This element performs certain functions in the nitrogen
metabolism, being present in nitrite reductase, hyponitrite
reductase, and reductases of nitrogen oxide. As a result of
the effect of copper on the biosynthesis of leg-hemoglobin
and the activity of some enzyme systems, this element
promotes fixation of atmospheric nitrogen and uptake of
nitrogen from the soil and fertilizers.

It has been reported in the literature that copper enhances
the stability of the chlorophyll-protein complex, minimizes
the degradation of chlorophyll in the dark, and, in general,
is favourable in the greening of all plants.

Since the copper-containing enzyme polyphenol oxidase
inactivates auxins, copper reduces the growth inhibiting
effect of large amounts of these growth substances. The black
pigment melanin results from oxidation of the amino acid
tyrosine, catalyzed by the enzyme tyrosinase which incorpo-
rates copper. A lack of this enzyme causes albinism. The
darkening of potatoes and apples damaged by rough han-
dling is also caused by tyrosinase.

Ethylene is known to slow down the differentiation of
tissues and inhibit cell division, DNA synthesis, and plant
growth. The biosynthesis of this substance calls for a copper-
containing enzyme. A decrease in the content of phenolic
inhibitors in plants leads to elongation of stalks and lodg-
ing of the plants. Apparently, by virtue of its regulatory
action on the content of phenolic growth inhibitors in
plants, copper enhances their lodging resistance. It also
increases the drought, frost, and heat resistance of plants.

Copper deficiency inhibits the growth of plants, makes
them susceptible to chlorosis, causes their loss of turgor
and wilting, delays flowering, and kills crops. Cereals suffer-
ing from acute copper deficiency have the tips of their leaves
whitened, and their ears fail to develop (white plague or

treatment disease), while fruit crops are blighted with dry
top rot under similar circumstances.

The overall copper content in various soils ranges widely
from 0.1 to 150 mg/kg of soil. It is the lowest in high moors
soddy calcareous soils of the Baltic republics, boggy and
waterlogged, sandy and sandy loam soils. Liming of acid
soils minimizes the uptake of copper by plants because such
treatment leads to its fixation in the soil. Lime acts as an
adsorber of copper and, through its alkalifying action, cre-
ates more favourable conditions for formation of complexes of
organic compounds with copper.

Plants suffer from copper deficiency and soils are consi-
dered to be copper-poor if soils in the Non-Black Earth zone
contain less than 1.5 to 3.0 mg/kg of copper, chernozems
contain less than 2.0 to 5.0 mg/kg, sierozems and chestnut
soils of Central Asia contain less than 1.5 to 4.0 mg/kg.

Copper requirements are high primarily in reclaimed
boggy soils.

Copper fertilizers are most effective when applied to peaty,
soddy gley, waterlogged, and light soils (Table 1.7).

Table 1.7. Effectiveness of Copper Fertilizers on the Peat-boggy Soils
of the Minsk Experimental Station

Crop	Yield (centners per hectare)	
	without copper	with copper
Spring wheat	3.8	15.2
Winter wheat	1.3	11.6
Barley	7.7	21.7
Oat	4.9	24.5
Millet	10.0	18.7

Because of copper deficiency, no yields of farm crops can
be obtained on some reclaimed peaty soils. Experimental
results indicate that application of copper fertilizers to
peat-boggy and light sandy loam soils increases the yield
of grain crops by two to five centners per hectare.

Especially responsive to copper fertilizers are wheat, oat,
and barley, followed by grasses, flax, hemp, root crops, red

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clover, millet, sunflower, mustard, sugar and fodder beets, fodder beans, pea, and vegetables. Copper requirements increase when nitrogen fertilizers are applied at high rates.

In the long run, the requirements of agriculture in this country for copper fertilizers can best be met by using blue vitriol (copper sulphate) and copper-potassium fertilizers.

Copper fertilizers of local importance include sulphur waste (0.2-0.3% Cu). It should be applied once in four to five years at a rate of five to six centners per hectare during ploughing in autumn or during presowing cultivation in spring.

Seeds are dusted with copper sulphate at a rate of 50 to 100 g per centner of seeds, the rate of foliar dressing being 200 to 300 g of copper sulphate per hectare. Copper sulphate contains 25.4% Cu (see Table 1.8).

Table 1.8. Copper Fertilizers

Fertilizer	Active ingredient	Active ingredient content in water-soluble form (%)
Blue vitriol (copper sulphate)	$CuSO_4 \cdot 5H_2O$	92.0-98.0
	Cu	23.4-24.9
Copper-containing powder	$CuSO_4$	14-16
	Cu	5-6
Sulphur waste	Cu	0.25
	K_2O	58.6±0.6

Manganese. The presense of manganese in plant organisms was discovered as far back as 1872, yet it has long been disregarded as a plant nutrient. Gedroits has demonstrated that manganese is more effective when used in combination with lime. The importance of manganese for plant nutrition was pointed out by Chirikov.

The most sensitive to available manganese content in the soil are cereals, beet, fodder root crops, and potatoes. 1000 to 4500 g of manganese are removed from a hectare by various crops (Table 1.9).

Manganese is necessary for all crops. The average content of manganese in plants is 0.001 per cent or 1 mg/kg fw. It is localized primarily in leaves and chloroplasts.

Table 1.9. Content of Manganese in Plants and Its Removal by Crops from Soddy Podsolic Soil and Deep Chernozem (according to Katalymov)

Crop	Soddy podsolic soil		Deep chernozem	
	yield (cent/ha)	Mn content (mg/kg)	yield (cent/ha)	Mn content (mg/kg)
Sugar beet:				
roots	542	88	280	50
tops	450	725	110	180
Potato:				
tubers	270	7	—	—
haulm	500	298	—	—
Oat:				
grain	22	88	20	56
straw	39	134	21	63
Spring vetch:				
hay	40	115	25	45
Barley:				
grain	20	40	15	30
straw	29	91	20	37

Manganese belongs to metals characterized by high redox potential and becomes easily involved in biological oxidation reactions.

Manganese has been found to take direct part in photosynthesis. The process rate was shown to be restored 20 minutes after manganese had been added to plants deficient in this nutrient. Manganese has also been found to be involved in the system of oxygen release during photosynthesis and to photosynthesize reduction reactions. Manganese increases the content of sugars, that of chlorophyll, its bonding with protein, promotes the efflux of sugars, and intensifies respiration.

The physiological role of manganese is best explained by its incorporation into hydroxylamine reductase initiating the reaction in which hydroxylamine is reduced to ammonia, as well as into an assimilation enzyme enabling carbonic acid to be reduced during photosynthesis. Manganese plays a major role in activating many reactions, including those of transformation of the di- and tricarboxylic acids forming in the course of respiration. It is believed that manganese

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is present in the enzyme synthesizing ascorbic acid. In
addition, manganese is a constituent of the following en-
zymes: malate dehydrogenase, isocitrated ehydrogenase, hyd-
roxylamine reductase, glutamine transferase, and ferredoxin.
Currently, 23 metal-enzyme complexes activated by manga-
nese are known.

Manganese is an essential component of the mechanism
of action of indoleacetic acid on cell growth. It has been
found to be indispensable as a cofactor of auxinoxidase for
enzymic degradation of indoleacetic acid. Manganese, just
as calcium, enables ions to be selectively absorbed from the
external solution. When manganese is excluded from the
nutrient medium, plant tissues accumulate the essential
inorganic nutrients, and the nutrient balance is upset. There
is evidence that manganese acts favourably on the transloca-
tion of phosphorus from the senescing lower leaves to the
upper ones and to reproductive organs. Manganese enhances
the water-holding capacity of tissues, reduces transpira-
tion, and affects fruit bearing.

Acute manganese deficiency has been found to cause bar-
renness in radish, cabbage, tomato, pea, and other crops.
It accelerates plant development. Manganese deficiency
makes plants susceptible to such diseases as chlorosis, grey
leaf spot (cereals), and yellows (sugar beet).

In spite of the high manganese content in the soil (up to
1% and above in yellow soils, 0.1-0.2% in soddy podsolic
soils and chernozems), most of this nutrient is present in
the form of poorly soluble oxides and hydroxides. At a soil
solution reaction close to neutral (pH 6-8), plants may suffer
from manganese deficiency because this nutrient passes into
poorly soluble compounds.

Manganese should be applied when its content is 25 to
55 mg/kg in soils of the Non-Black Earth zone, 40 to 60
mg/kg in chernozems, and 10 to 50 mg/kg in sierozems.

Manganese fertilizers should be used to treat first of all
grey forest soils, slightly leached chernozems, alkaline and
chestnut soils occupied by oat, wheat, fodder root crops,
potatoes, sugar beet, maize, alfalfa, sunflower, fruit and
berry crops, citruses, and vegetables.

Manganese requirements are highest in the Ukraine,
Central Asia, and Transcaucasia.

Perennial experiments on different soils have shown that manganese fertilizers increase the yield of winter and spring wheat by 1.5 to 3 centners per hectare.

On Ukrainian chernozems, the increase in sugar beet yield due to manganese fertilizers is 10 to 15 centners per hectare, the sugar content in roots increasing by 0.2 to 0.6 per cent, while the yield of grain crops, including winter wheat, increases by 1.5 to 3 centners per hectare (Table 1.10).

Table 1.10. Effect of Manganese on Crop Yields (according to Vlasyuk)

Crop	Yield without Mn application (cent/ha)	Yield increase due to Mn (cent/ha)
Sugar beet (roots)	310	23.7
Winter wheat (grain)	33.4	2.1
Spring wheat (grain)	17.5	2.2
Maize (grain)	57.8	11.8
Barley (grain)	11.9	3.0

Manganese fertilizers are essentially manganese ore processing waste, which usually contains 10 to 18% Mn. The expensive manganous sulphate is typically used for hothouse vegetable growing. In view of the fact that the effectiveness of manganese is maximum when it is applied in combination with phosphorus fertilizers, it is worthwhile to produce manganese superphosphate (see Table 1.11).

Table 1.11. Manganese Fertilizers

Fertilizer	Active ingredient	Percentage content in water-soluble form
Manganese superphosphate	P_2O_5-Mn	20±1 1-2
Manganous sulphate	$MnSO_4$	70
Manganese-containing powder	$MnSO_4$	18-22

The application rate in terms of manganese is 2.5 kg/ha. About 30 per cent of the manganese fertilizers used in agriculture is in the form of manganous sulphate applied for

foliar dressing and presowing treatment of seeds. One of the manganese application techniques is dusting of seeds. To this end, 50 to 100 g of manganous sulphate are mixed with 300 to 400 g of talc, and the mixture is used to treat one centner of sugar beet, wheat, maize, and pea seeds. The foliar dressing rate is 200 g of manganous sulphate per hectare, while fruit and berry crops are sprayed at rates ranging from 600 to 1000 g per hectare.

Molybdenum. The molybdenum content in plants is the highest in legumes; seeds of leguminous grasses may contain anywhere from 0.5 to 20 mg Mo/kg dw, and cereals contain 0.2 to 1.0 mg Mo/kg dw. The molybdenum content in plants may vary from 0.1 to 300 mg/kg dw; increased content may be caused by unbalanced nutrition.

Plants require molybdenum in smaller amounts, as compared to boron, manganese, zinc, and copper. Molybdenum is localized in young, growing organs. Leaves contain more molybdenum than stalks and roots, most of it being concentrated in leaf chloroplasts.

The lower limit of molybdenum content in plants is accepted to be 0.10 mg/kg dw for most species and 0.40 mg/kg for legumes. Anything below this limit is considered as molybdenum deficiency.

An average yield of wheat removes up to 6 g of molybdenum per hectare, the removal rate increasing to 10 g/ha for clover.

Molybdenum in plants is a constituent of the enzyme nitrate reductase and represents an indispensable link in the nitrate reduction chain, whereby nitrates are reduced to nitrites. Molybdenum may be regarded as a micronutrient involved in the nitrogen metabolism in plants for it is also found in nitrogenase, the enzyme performing the function of atmospheric nitrogen fixation in the biological nitrogen cycle.

The involvement of molybdenum in the fixation of atmospheric dinitrogen explains its special role as a promoter of growth and development of leguminous crops.

Experiments have shown that molybdenum deficiency in the nutrient medium upsets nitrogen metabolism in plants with a large amount of nitrates accumulating in their tissues. Uptake of excessive quantities of molybdenum by animal

and human organisms leads to formation of such carcino-
gens as nitrosoamines. Our data indicate that molybdenum
is involved in nitrogen metabolism not only through its
incorporation into nitrate reductase and nitrogenase. Mo-
lybdenum increases the activity of dehydrogenases in the
nodules of leguminous crops—enzymes ensuring a contin-
uous influx of hydrogen necessary for fixation of atmo-
spheric nitrogen.

A wealth of experimental evidence is now available, at-
testing to participation of molybdenum in certain physiolog-
ical processes occurring in plants (nucleic acid synthesis,
photosynthesis, respiration, synthesis of pigments, vitamins,
etc.). It appears to exert an indirect but strong influence on
these processes via the metabolic system.

The specific role of molybdenum in nitrogen fixation
accounts for improved nitrogen nutrition of leguminous
crops treated with molybdenum fertilizers and enhances
effectiveness of the phosphorus and potassium fertilizers
applied in combination with them. This increases not only
yields but also the protein content. Treatment of non-legu-
minous crops with molybdenum, which facilitates the assim-
ilation of nitrate nitrogen, enhances the rate and extent of
nitrogen uptake by farm crops both from fertilizers (not
only nitrates but also ammonia and amide fertilizers by
virtue of their rapid nitrification) and from the soil as well
as minimizes unproductive nitrogen losses due to denitrifi-
cation and leaching of nitrates. This has been convincingly
demonstrated in ^{15}N experiments with vegetables and cot-
ton.

Sensitive to deficiency of available forms of molybdenum,
often observed in acid soils, are alfalfa, clover, pea, beans,
vetch, cabbage, lettuce, spinach, and other crops. The
manifestations of moderate molybdenum deficiency in legumes
are similar to those of lack of nitrogen. A more acute
molybdenum deficiency sharply inhibits plant growth, root
nodules fail to develop, plants acquire pale green coloration,
leaf blades are deformed, and leaves wilt prematurely.

High molybdenum rates are extremely toxic for plants.
High contents of this element in farm produce are harmful
for animals and man. It is believed that molybdenum in a
concentration of one milligram per kilogram of dry weight

adversely affects man and animals alike. In cases where the
molybdenum content in plants reaches 20 mg/kg dw and
more, animals feeding on fresh plants suffer from molybde-
num toxicoses and man, from endemic gout. The toxic effect
of molybdenum is mitigated when plants are dried or frozen,
which minimizes the content of its soluble forms. Another
means to mitigate this toxic effect is by adding copper to
the food eaten by animals and man.

Crops responsive to application of molybdenum fertilizers
include alfalfa, clover, soybean, fodder beans, vetch, cauli-
flower, root crops, rape, fodder cabbage, and vegetables.

The total molybdenum content in the soil ranges from
0.20 to 2.40 mg/kg of soil, and that of available forms, from
0.10 to 0.27 mg/kg. Usually, available forms of molybdenum
in the arable layer constitute 8 to 17 per cent of its total
content. The smallest amounts of molybdenum are in light
humus-poor soils. The lowest mobile molybdenum content
has been found in soddy podsolic and sandy soils
(0.05 mg/kg). The higher content of total and mobile molyb-
denum in chernozems is indicative of its biological accumu-
lation.

Molybdenum is normally present in the soil in an oxidized
form, namely, molybdates of calcium and other metals.
In acid soils, molybdenum forms poorly soluble compounds
with aluminium, iron, and manganese, while in alkaline
soils, it forms the readily soluble sodium molybdate.

The quantity of water-soluble forms of molybdenum in-
creases with decreasing acidity of the soil solution. The
uptake of this nutrient by plants growing on limed soils
increases, but at pH 7.5-8.0 the uptake rate starts going
down because of the greater amounts of carbonates forming
in the soil.

Molybdenum deficiency may occur on soddy podsolic
soils, reclaimed acid moors, and chernozems.

The positive effect of molybdenum on the yields and quali-
ty of vegetable crops stems not only from its acting as a
promoter of fertilizer nitrogen uptake, but also as an agent
improving the uptake of soil-derived nitrogen (Table 1.12).

The improved nitrogen nutrition of plants under the effect
of molybdenum is conducive, in turn, to a more intensive
uptake of other inorganic nutrients, including phosphorus

Table 1.12. Effect of Molybdenum on the Uptake of Soil-Derived and Fertilizer Nitrogen from Soddy Podsolic Soil by Lettuce (according to Muravin)

Experimental conditions	Uptake in two successive plantings within a year (averaged over two years)				
	total	from the soil		from fertilizer	
	mg/vessel	mg/vessel	% of PK	mg/vessel	% of applied amount
PK	514	514	100	—	—
PK + Mo	612	612	119	—	—
NPK	992	712	134	280	39
NPK + Mo	1158	821	158	337	47

and potassium, both from the soil and fertilizers. Application of molybdenum to soils suffering from its deficiency not only increases crop yields, but also ensures a more complete incorporation of the nitrogen taken up by the plants into their proteins, and minimizes the danger of accumulation in farm produce, particularly vegetables and range forage, of nitrates in amounts toxic for man and animals, which may occur in the case of high nitrogen fertilizer rates and on organogenic soils with intensive mineralization of nitrogen. All this makes it expedient to apply molybdenum in combination with single and compound nitrogen fertilizers for treating non-leguminous crops requiring molybdenum and with phosphorus-potassium ones for treating legumes grown on soils where this nutrient is more or less deficient.

Field experiments indicate that the average pea yield increase due to molybdenum on soddy podsolic and grey forest soils as well as leached chernozems is 2.6 centners per hectare, while those of clover hay and seeds on soddy podsolic soils are 13 and 0.8 centners per hectare, respectively (Table 1.13).

Molybdenum is effective when applied to legumes grown on acid soils. As a result of intensified symbiotic nitrogen fixation by legumes under the effect of molybdenum, crops are better supplied with nitrogen and yields increase along with the protein content in the crops. If other nutrients are

Table 1.13. Average Legume Crop Yield Increases (cent/ha) Due to Molybdenum (data from the USSR Research Institute of Fertilizers and Agronomical Soil Science)

Crop	Soddy podsolic soils		Grey forest soils	
	number of runs	increase due to Mo	number of runs	increase due to Mo
Pea (seeds)	34	2.9	22	3.6
Vetch (seeds)	10	5.1	14	4.9
Vetch (forage)	2	34.0	9	51.6
Soybean (seeds)	13	2.7	1	1.9
Fodder beans (seeds)	22	4.9	5	3.2
Clover (hay)	58	13.0	—	—
Clover (seeds)	18	0.8	—	—
Alfalfa (seeds)	15	9.3	9	18.2

present in sufficient amounts, molybdenum fertilizers are highly effective when the molybdenum content is less than 0.15 mg/kg in soils of the Non-Black Earth zone, less than 0.15 to 0.30 mg/kg in chernozems, and less than 0.20 to 0.55 mg/kg in chestnut soils and sierozems. Treatment of grass and legume haylands and pastures with molybdenum fertilizers increases the percentage of legumes in the plant stand, the protein content in the feed, and the overall productivity of the grass lands (Table 1.14).

Table 1.14. Effect and Aftereffect of Molybdenum on the Yield and Botanical Composition of Grasses (according to Sharov)

Experimental conditions	Hay yield (cent/ha)		Botanical composition of the plant stand (%)		
	effect	aftereffect	legumes	grasses	forbs
No molybdenum	24.6	25.1	27	46	27
Foliar dressing with molybdenum (150 g/ha)	32.0	34.9	43	35	22

The nomenclature of molybdenum fertilizers is rather extensive (Table 1.15), the major commercially produced

Table 1.15. Molybdenum Fertilizers

Fertilizer	Active ingredient	Percentage content of active ingredient in water-soluble form
Ammonium molybdate	Mo	52 ± 1
Molybdenum-containing powder	MoO_3	14.5-16.5
Waste of electric lamp industry	Mo	5-8
Ordinary pelletized superphosphate with molybdenum	P_2O_5 Mo	20 ± 1 0.1
Double pelletized superphosphate with molybdenum	P_2O_5 Mo	43 ± 1 0.2 ± 0.05

fertilizer being ammonium molybdate.

In some republics, molybdenum waste of the electric lamp industry is used as fertilizer.

As regards applications of molybdenum fertilizers, the most effective and economical is presowing treatment of seeds (Table 1.16). To treat one centner of large seeds re-

Table 1.16. Application of Molybdenum Fertilizers

Fertilizer	Crop	Dosage	Application
Molybdenum superphosphate (0.2% Mo)	Pulses	50 kg/ha to be drilled at seeding	Drilling
Ammonium molybdate (50% Mo)	Pea, vetch, soybean, and other large-seed crops	25-50 g in 1.5-2 litres of water per centner of seeds	Presowing treatment of seeds
Ditto	Clover, alfalfa	500-800 g in 3 litres of water per centner of seeds	Ditto
Ditto	Pea, fodder beans, clover, alfalfa, and other legumes cultivated for seeds	200 g in 100 litres of water (aerial spraying)	Foliar dressing at budding and early flowering stages

quires 25 to 50 grams of ammonium molybdate or ammonium-sodium molybdate, while treatment of one centner of clover or alfalfa seeds takes 500 to 800 grams.

Foliar dressing is carried out at a rate of 200 g of ammonium molybdate per hectare. A promising form of fertilizer is molybdenized superphosphate intended for drilling at a rate of 0.5 cent/ha (or 50-100 g of molybdenum per hectare).

Zinc. Field crops remove anywhere from 75 to 2250 g of zinc from a hectare.

High sensitivity to zinc deficiency is exhibited by such crops as buckwheat, hop, beet, potatoes, and red clover. Weeds are characterized by a higher zinc content, as compared to cultivated plants. Large amounts of zinc are found in coniferous plants, its content being the highest in poisonous fungi. Field crops require less zinc than fruit trees.

Zinc enhances heat and frost resistance of plants by stabilizing to some extent their respiration during sharp temperature changes. There is evidence that zinc affects the uptake of phosphorus by plants. When zinc is deficient, plants accumulate large amounts of inorganic phosphorus. Pea and tomatoes take up more phosphorus, but its utilization is upset so that the inorganic phosphorus content increases several-fold at the expense of the phosphorus present in nucleotides, including those with high-energy bonds, and also lipids and nucleic acids. Addition of zinc to the nutrient solution brings the utilization of phosphorus taken up by plants back to normal.

There have been reports that zinc changes the rate of phosphorus accumulation by roots and slows down phosphorus translocation into the above-ground organs. Zinc is also known to be fixed in the soil by phosphorus compounds. Zinc deficiency inhibits the conversion of inorganic phosphates into organic forms.

Of particular interest is the role of zinc in the biosynthesis of chlorophyll precursors and in photosynthesis. Etiolated and green leaves of maize have been found to contain zinc-protoporphyrin which may be a precursor of iron-porphyrins and, possibly, magnesium-porphyrin. As opposed to Mn, Cu, and Fe, zinc has not been observed to be directly involved in photosynthetic reactions, although it is known to contribute to formation of chlorophyll precursors,

The zinc-containing enzyme carbonic anhydrase may perform certain functions in photosynthesis. Its role in green plants boils down to trapping the carbonic acid which may be released into the atmosphere in the course of photorespiration. Carbonic anhydrase apparently enables carbonic acid to pass across the chloroplast envelope by catalyzing the synthesis, and the dehydration, of carbonic acid from, and to, carbon dioxide and water.

At present, more than 30 zinc-containing enzymes are known. The respiratory enzyme carbonic anhydrase contains 0.31-0.34% Zn. Zinc is also a constituent of alkaline phosphatase, malate dehydrogenase, alcohol dehydrogenase, glutamate dehydrogenase, and other enzymes. Many metal-enzyme complexes (about 20) are activated by zinc. The zinc-containing carbonic anhydrase has been found in oat, parsley, pea, and in the chloroplasts of tomatoes. Zinc is a component of most, if not all, dehydrogenases requiring NAD. The incorporation of zinc in glycolytic and respiratory enzymes, many NAD- and some FAD-dependent enzymes explains its role in glycolytic and respiratory cycles.

When zinc is deficient, plants tend to accumulate reducing sugars with diminishing sucrose and starch contents, increasing organic acid content, decreasing auxin content, and upsetting protein synthesis. Another consequence of zinc deficiency is accumulation of soluble nonprotein nitrogen compounds, such as amides and amino acids.

Zinc deficiency strongly (by a factor of 2 or 3) inhibits cell division, which leads to morphological changes in leaves, upsets the elongation of cells and differentiation of tissues, hypertrophies meristematic cells, suppresses the elongation of columnar cells in flax, and reduces the size of its chloroplasts. A lot of mitochondria are formed in the presence of zinc.

Highly sensitive to zinc deficiency are fruit and, especially, citrus crops. Apple, apricot, peach, quince, and cherry trees suffer from little-leaf and rosette diseases, while citruses are afflicted with leaf spot. The upper leaves of maize undergo blanching or chlorosis, when zinc is deficient, while tomato leaves become small and leaf blades together with petioles curl. All plants experience stunted growth as a result of lack of zinc.

Zinc deficiency may occur on acid highly podsolized light soils and zinc-poor calcareous and highly humified soils. It is aggravated by application of high rates of phosphorus fertilizers and ploughing that brings the subsoil close to the topsoil. The highest total zinc content has been found in tundra soils (53-76 mg/kg) and chernozems (24-90 mg/kg), and the lowest, in soddy podsolic soils (20-67 mg/kg). Zinc deficiency is more typical of neutral and weakly alkaline calcareous soils. In acid soils, zinc is more mobile and available.

Zinc fertilizers should be used when the mobile zinc content is less than 0.2 to 4.0 mg/kg in soils of the Non-Black Earth zone, less than 0.3 to 2.0 mg/kg in chernozems, and less than 1.4 to 1.8 mg/kg in sierozems and chestnut soils of Central Asia.

Zinc fertilizers include some industrial waste, zinc sulphate (containing 22% Zn), and polymicronutrient fertilizers (PMU-7), which are essentially waste of zinc white production. They contain 19.6% ZnO, 17.4% zinc silicate, 21.1% alumina, and small amounts of aluminium, copper, and manganese (Table 1.17).

Table 1.17. Zinc Fertilizers

Fertilizer	Active ingredient	Active ingredient content in water-soluble form (%)
Zinc sulphate	Zn	21.8-22.8
Zinc-containing powder	$ZnSO_4$	18-22
Zinc polymicronutrient fertilizers (PMU-7)	Zn	2-5

To treat maize, PMU-7 is drilled at a rate of 20 kg/ha. Zinc sulphate is used for foliar dressing (150-200 g/ha). The dressing is intended for most crops at the budding or early flowering stages. Fruit trees are sprayed in spring when their leaves have just unfolded (200-500 g of zinc sulphate in 100 litres of water plus 0.2-0.5% of hydrated lime for neutralizing the acidity of the salt solution to avoid leaf burns). To sprinkle one centner of seeds, 4 g of zinc sulphate are dissolved in 4 litres of water. Dusting of one centner of

maize seeds requires 400 g of the polymicronutrient fertilizer (PMU-7).

Application of zinc is important in treating calcareous chernozems, chestnut and brown soils, and sierozems. Zinc fertilizers are most effective when applied to cotton, sugar beet, maize, and especially fruit crops.

Cobalt. The average content of cobalt in plants is 0.00002 per cent or about 0.021 mg/kg dw. Sometimes it may reach 11.6 mg/kg dw.

A lot of cobalt is present in legumes where it is localized in nodules. Cobalt is also localized in generative organs, being accumulated in pollen, thereby accelerating its germination. About 50 per cent of the cobalt present in plants is in the ionic form, while 20 per cent is in the form of cobamides and in vitamin B_{12}. The latter is synthesized by microorganisms and is taken up by plants from the soil or is accumulated in the nodules of nitrogen-fixing plants. It has been found in legumes, turnip, pea, and onion. Unidentified highly stable organic compounds constitute about 30 per cent.

An activated or coenzymic form of vitamin B_{12} has been isolated, known as 5.6-dimethylbenzimidazolecobamide coenzyme. In combination with aspecific protein, this coenzyme forms methylmalonyl isomerase, which catalyzes conversion of propionates into succinates.

Cobalt-methylcorrinoid may serve as a donor of methyl groups for methylation of tRNA. B_{12}-coenzyme-dependent ribonucleotide reductase has been found. Cobamide coenzymes are involved in DNA synthesis and cell division. The methylation reaction is essential for many processes and, more particularly, for improving the resistance of plants to some diseases. For example, the agent causing fusarium wilt produces a toxin known as fusaric acid. Methylation yields a non-toxic methylamide derivative.

Cobalt belongs to metals of variable valence, which is why the redox potential of the Co^{3+}-Co^{2+} couple in an acidic medium is high and the cobalt ion is actively involved in redox reactions. However, no cobalt has been found in the active groups of respiratory or photosynthetic enzymes.

According to some reports, cobalt is associated with auxin metabolism and promotes elongation of cell envelopes.

Cobalt is necessary to legumes in the absence of fixed nitrogen. Cobalt requirement constitutes 1/330 of that for molybdenum, while for nitrogen fixation cobalt is required in an amount one tenth of what is necessary for the growth of nodules. Cobalt alters the ultrastructure of the nitrogen-fixing apparatus so that bacteroids remain actively functional for a longer period of time. Capsules around bacteroids take shape earlier and keep it longer.

Cobalt exerts substantial positive influence on the reproduction of nodule bacteria.

Our findings indicate that one of the functions performed by cobalt in connection with nitrogen fixation is its participation in leg-hemoglobin biosynthesis. Experiments have shown that cobalt activates dehydrogenases, hydrogenase, and nitrate reductase, increases the content of chlorophyll, total hematin, and vitamin E genetically associated with chlorophyll.

Thus, cobalt affects the nitrogen-fixing system and other physiological processes as well.

Cobalt has been found to be indispensable for legumes and wheat. There is a wealth of data to support the positive effect of this nutrient on the yield of many crops. It manifests itself primarily on soils abundant in the rest of inorganic nutrients and having a reaction close to neutral. Application of cobalt-containing fertilizers is promising on chernozems, cultivated soddy podsolic soils, sierozems, and chestnut soils. They are effective when used to treat pulses and grape grown on chernozems. Application of cobalt is very important to enhance the nutritive value of farm products as a result of its increased content in crops. It has been demonstrated that, when the cobalt content in feeds is less than 0.07 mg/kg of dry hay, animals suffer from cobalt deficiency. Therefore, cobalt-containing fertilizers should be applied to meadows and pastures in areas of cobalt deficiency.

Application of cobalt-containing fertilizers improves the quality of crops not only because they accumulate large amounts of this nutrient, but also due to other factors. For example, in experiments carried out on soddy podsolic soils, the yield of sugar beet roots, averaged over 44 trials, increased by 35 centners and their sugar content increased by

0.8 per cent, whereby the yield of sugar increased by 10 centners per hectare.

The increase in the yield of lupine on soddy podsolic soils due to cobalt-containing fertilizers was 1.2 cent/ha in terms of seeds and 65 cent/ha in terms of forage (the yield on the control plot was 325 cent/ha).

Cobalt-containing fertilizers are effective when this nutrient is present in an amount of 1.0 to 1.1 mg/kg in soils of the Non-Black Earth zone, 0.6 to 2.0 mg/kg in chernozems, and 1.0 to 1.5 mg/kg in sierozems and chestnut soils of Central Asia. However, to obtain high-quality animal feeds and foodstuffs, these fertilizers must be used when the cobalt content in the soil is 2.0 to 2.5 mg/kg. Cobalt may be applied to the soil at a rate of 200 to 400 g/ha in terms of Co. For foliar dressing and presowing treatment of seeds, 0.01-0.1 % solutions of cobalt sulphate are used.

Trends in Application of Micronutrient Fertilizers. The importance of micronutrients in raising the productivity of farm crops and steadily increasing demands for the latter make it imperative to supply farms with advanced forms of micronutrient fertilizers ensuring effective utilization of these nutrients by plants.

An absolute lack of some micronutrients and a low content of their available forms in soils may be one of the factors limiting the increase in crop yields. Suffice it to mention copper deficiency in peaty soils, that of molybdenum in acid soddy podsolic and grey forest soils, and the deficiency of boron and molybdenum in red soils, iron and zinc in calcareous and sandy loam soils.

The systematic increase in crop yields due to intensive chemicalization of agriculture goes hand in hand with increased yield removal of all inorganic nutrients, including micronutrients, which renders application of micronutrient fertilizers even more necessary.

The deficiency of certain micronutrients in soils reduces the effectiveness of nitrogen, phosphorus, and potassium fertilizers, whereas application of micronutrient fertilizers does the opposite.

The results of numerous experiments aimed at finding promising types and forms of micronutrient fertilizers testify to the expediency of their manufacture and application,

including those of compound fertilizers. Field trials of ex-
perimental and pilot batches of basal fertilizers with micro-
nutrients have shown that, for example, addition of boron
alone to nitroammophoska applied to leached chernozems
and soddy podsolic soils provides for the following yield
increases: 30 to 40 centners per hectare of sugar beet roots,
2.3 to 2.9 centners of cabbage seeds, and 2.1 to 3.7 centners
of pea seeds. Application of molybdenum incorporated into
superphosphate to soddy podsolic soils increases the yield
of leguminous grass hay by 5 to 6 centners per hectare. In
the case of acute copper deficiency (reclaimed peat-boggy
soils in lowlands), cereals produce virtually no grain when
treated with basal fertilizers, while application of potas-
sium chloride enriched with copper increases the yield of
barley grain by 25 to 30 cent/ha, that of grasses by 15 to
18 per cent, and that of vegetables by 20 per cent.

Application of micronutrients together with basal fertil-
izers is also justified economically (Table 1.18).

According to estimates, 60 to 70 per cent of the require-
ments of farms for micronutrients must be met by those used

Table 1.18. Economic Efficiency of Using Micronutrients As Part of
Compound Fertilizers

Crop	Fertilizer	Yield in-crease due to micro-nutrient, expressed in rubles	Additional expenses in-curred in buying the fertilizer and harvesting (in rubles)	Nominal net return (in rubles per ha)
Sugar beet	Nitroammophoska + boron	90	24	66
Fibre flax	Ditto	98	33	65
Cabbage	Nitroammophoska + molybdenum	157	81	76
Clover	Phosphorus-potassi-um fertilizer + mo-lybdenum	27	7	20
Cotton	Ammophos + manga-nese	176	37	139
Wheat	Ditto	17	5	12
Barley	Potassium fertil-izers + copper	53	6	47
Wheat	Ditto	84	5	79

in combination with basal fertilizers and 30 to 40 per cent, by their commercial salts used in foliar dressing and presowing treatment of seeds.

The need for balanced nutrition of crops with all nutrients to ensure maximum yields of quality crops not only does not rule out but, on the contrary, makes it imperative to use a strictly differentiated approach to application of micronutrients with due account for the amounts of available micronutrients present in the soil, other soil and climatic factors, biological and nutritive characteristics of the crops.

Application of a broad range of micronutrients in combination with macronutrients as part of compound fertilizers or nutrient mixtures must be restricted and permissible only in complete absence of nutrients in the case of crops grown on infertile sandy and sandy loam soils, hydroponics, crops grown on sheltered ground using inert low-buffer media, horticulture, and ornamental gardening.

In such cases, however, there must be scientifically sound reasons for joint application of macro- and micronutrients in view of the fact that the interaction between them may be not only synergic but also antagonistic. The latter is exemplified by copper and phosphorus, phosphorus and zinc, copper and molybdenum, copper and zinc.

Extensive acid soil reclamation programs increase the requirements of farm crops for molybdenum and vanadium. The availability of these micronutrients is largely determined by liming and high rates of inorganic fertilizers.

Another factor of importance insofar as the mobility and availability of micronutrients are concerned is the changing soil reaction under the effect of the physiological acidity or alkalinity of inorganic fertilizers.

Systematic application of organic fertilizers at high rates usually increases the overall reserves of micronutrients in the soil as well as the content of their mobile forms. However, application of manure from farms where individual micronutrients are added to cattle and poultry feeds calls for careful selection of their rates in each particular case.

When industrial waste, composted town refuse, sewage sludge, and high rates of liquid manure are used as local fertilizers there is a danger of individual microelements (including heavy metals) being accumulated in the soil and

becoming involved in the biological cycle in concentrations toxic to plants, animals, and man.

With steadily increasing rates of nitrogen fertilizers, serious attention must be paid to the use of the micronutrients taking part in the reduction of nitrates and other processes associated with assimilation of nitrogen by plants so as to enhance the efficiency of fertilizer nitrogen utilization and to minimize the danger of accumulation of nitrates in farm produce and contamination of water, including that used for drinking, with them. There is ample evidence that molybdenum actively promotes utilization of fertilizer and soil-derived nitrogen.

Heavy application of nitrogen to various crops increases their requirements for molybdenum, copper, boron, and cobalt.

Particular attention should be given to those aspects of agrochemical studies involving micronutrients which are of primary importance for practical uses of micronutrients in agriculture, ensuring their maximum agrochemical and economical efficiency.

These include:

development of reliable methods for predicting the effectiveness of micronutrient fertilizers, based on agrochemical analysis of soils for content of available forms of micronutrients and crop diagnosis;

investigation of the effect of advanced forms of micronutrient fertilizers applied in combination with increasing rates of basal (NPK) fertilizers on the yields and quality of major farm crops, undertaken within the framework of the geographic field experiment network using standard methods and programs;

studying the balance of macro- and micronutrients in perennial experiments with fertilizers and crop rotation in various soil and climatic zones of the country, including experiments in which micronutrient fertilizers are incorporated into the fertilizer system;

studying the interaction between macro- and micronutrients in assimilation and metabolic processes, as well as the effect of micronutrients (micronutrient fertilizers) on the extent and rate of uptake of the basal soil-derived and fertilizer nutrients.

Item one in this list includes determination of the maximum micronutrient contents in soils and plants, elaboration of improved methods for determining the contents of available forms of micronutrients in plants, a scientific classification of soils by different soil and climatic zones and geographic regions in terms of their micronutrient contents, depending on crops, types, texture and other properties of soils, organic and inorganic fertilizer application rates, as well as water management procedures.

Along with studies into the effectiveness of advanced forms of compound fertilizers containing micronutrients over a long period of time, it is also important to develop techniques for optimizing the use of micronutrient-containing industrial waste and to search for raw materials suitable to produce micronutrient fertilizers.

Studies of the balance of macro- and micronutrients in perennial experiments with crop rotation must go hand in hand with investigation of the effect of systematic application of high rates of organic and inorganic fertilizers, chemical amelioration, and use of plant protection chemicals on the content and availability of soil-derived and fertilizer micronutrients.

Another area of interest includes research involving micronutrients previously unknown from the standpoint of agricultural chemistry (iodine, lithium, aluminium, vanadium, titanium, selenium, rubidium, bromine, and fluorine), as well as determination of the possible negative effect of some micronutrients (such as copper, fluorine, arsenic, chromium, and lead) in the context of technogenic pollution and environmental control.

There is no doubt that the above aspects of agrochemical studies of micronutrients do not cover all the problems associated with their use in agriculture. Yet they are of primary importance in the research activities of Soviet scientists who are looking for the most rational ways of applying micronutrient fertilizers.

Compound Fertilizers

Fertilizers are referred to as compound if they contain two, three, and more nutrients, such as nitrogen, phosphorus, potassium, magnesium, and micronutrients, in different combinations and ratios.

Distinction is made between binary (phosphorus-potassium, nitrogen-phosphorus, and nitrogen-potassium) and ternary (NPK) fertilizers.

Depending on the way in which they are produced, compound fertilizers may be multiple, mixed multiple, and mixed, and, according to their state of aggregation, fertilizers may be solid and liquid.

Multiple fertilizers contain at least two nutrients and are produced in a single process based on a chemical interaction (reaction) between ammonia, phosphoric, nitric or sulphuric acid, ammonium nitrate, phosphorite or apatite melt, potassic salts, and other starting components.

Mixed miltiple fertilizers result from blending of simple fertilizers ready for use, with addition of liquid and gaseous products. For example, a mixed fertilizer is produced by ammoniation of ordinary superphosphate or nitrates and potassic salts with addition of phosphoric or sulphuric acid.

Mixed fertilizers are produced by blending two or more single fertilizers.

The many processes used in the production of compound fertilizers can be divided into the following four groups:

(1) Production of solid multiple fertilizers, involving phosphoric and polyphosphoric acids.

(2) Production of liquid compound fertilizers, involving phosphoric and polyphosphoric acids.

(3) Production of solid compound fertilizers, involving treatment of phosphorite rock with nitric acid.

(4) Production of mixed and mixed multiple fertilizers.

The high concentration and diversity of nutrients are among the major advantages of compound fertilizers. For example, ammophos, diammophos, ammoniated superphosphate, carboammophos, and nitrophos contain two nutrients, while nitrophoska, nitroammophoska, and carboammophoska contain three. Some compound fertilizers also contain micronutrient additives.

Calculations have shown that, when single fertilizers are applied separately two or three times, the expenses involved in their preparation and application are one and a half to two times as high as in the case of compound fertilizers, to say nothing of the often upset optimal nutrient ratio.

An increase in the content of nutrients in fertilizers by a mere ten per cent permits about 5 million ton-kilometres to be saved in transportation.

As was shown in experiments, when nitrogen, phosphorus, and potassium were supplied separately (via individual root bundles), maize grew worse and took up less P_2O_5, as compared to joint application and uptake of these nutrients.

Early experimental results attesting to a more intensive uptake of phosphorus applied together with nitrogen and potassium were corroborated in experiments with compound fertilizers.

Compound fertilizers ensure better position availability of nutrients to the root system.

Their application more fully meets the nutrient requirements of crops and permits saving the expenses incurred in transportation, building of storage facilities, and use of machinery for their handling and application.

A comparison of different types of compound fertilizers with equivalent combinations of single ones has revealed that the former better promote the development and maturation of all rotating crops. Calculations indicate that, even when the wholesale price of nitroammophoska is somewhat higher than that of equally effective single fertilizers, the higher concentration of nutrients in it (48% as compared to 27% in mixtures of single fertilizers) and the respectively low cost of its transportation, storage, preparation, and application make the overall cost of application of compound fertilizers to every hectare under treatment lower

than that of single ones. This conclusion is shared by many investigators.

According to some research workers, compound fertilizers produce in most cases a more beneficial effect on the crop quality than mixtures of single fertilizers.

As regards the nutrient ratios to be maintained in compound fertilizers, some indications are given by the experimental data summarized in Table 2.1.

Table 2.1. Nutrient Ratios and Percentage Content in Compound Fertilizers

| $N : P_2O_5 : K_2O$	Percentage content	Target crops and soils
1 : 1 : 1 (nitrophoska type)	32.0	Most crops and soils at equal effectiveness of the three nutrients
1 : 1.5 : 1	11.1	Soils with acute deficiency in available phosphorus and moderate amounts of nitrogen and potassium
1 : 1 : 1.5	6.6	Soils extremely poor in potassium and potassium-loving crops (potatoes, sugar beet, etc.) grown on other soils
1 : 1.5 : 1.5	6.3	Crops sown after perennial leguminous grasses and grass mixtures (e. g. fibre flax grown on soddy podsolic soils)
1 : 1 : 0.5	1.7	Soils with high available potassium content and crops removing small amounts of potassium (e. g. grain crops grown on leached chernozems)
1 : 2.5 : 0	6.2	For starter and basal application to cotton (when soils are not deficient in potassium)
1 : 4 : 0	5.6	For starter application to cereals and basal application to soils in the southern parts of the country (ordinary and southern chernozems, unirrigated chestnut soils, etc.)
1 : 1 : 0 (nitroammophos type)	1.3	Cereals and other crops grown on soils abounding in available potassium
0 : 1 : 1	6.5	Cereals and other crops grown on soils abounding in available nitrogen
0 : 1 : 1.5	3.3	Same as above plus soils more deficient in potassium than in phosphorus
Others	19.4	According to recommendations of the agrochemical service

2.1 Multiple Fertilizers

This group includes binary (ammonium polyphosphate, ammophos, diammophos, nitroammophos, nitrophos, carboammophos, urea phosphates, and phosphorus-potassium fertilizers) and ternary (nitrophoska, nitroammophoska, and carboammophoska) fertilizers.

Ammophos, $NH_4H_2PO_4$, or monoammonium phosphate. The ions (ammonium and phosphate) constituting this salt are required by all crops and are readily taken up by them on all soils. Ammophos contains 11-12% N and 46-60% P_2O_5. It contains no dead weight. Its production process is rather simple and boils down to neutralization of ammonia with phosphoric acid:

$$NH_3 + H_3PO_4 = NH_4H_2PO_4$$
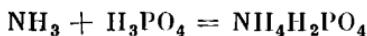
Ammophos has a drawback, though: the nitrogen to phosphorus ratio in it is rather wide—1 : 4 or even 1 : 5. This restricts the applicability of ammophos because the nitrogen to phosphorus ratio in a fertilizer must be close to unity since most plants require even more nitrogen than phosphorus.

Diammophos, $(NH_4)_2HPO_4$. Ammophos is produced by saturating free phosphoric acid with ammonia. If this process is continued, the end product will be diammophos in which the nitrogen to phosphorus ratio is about 1 : 2.5:

$$2NH_3 + H_3PO_4 = (NH_4)_2HPO_4$$
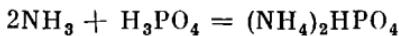
Diammophos contains 18% N (sometimes more) and about 50% P_2O_5. The total content of nitrogen and phosphorus in this fertilizer exceeds 70 per cent. This is the most concentrated of all compound fertilizers.

In addition to the economical advantages typical of all high-analysis fertilizers, ammonium phosphates are also ideal for local application during sowing and planting of all crops, being placed in proximity to seeds. They do not contain any perceptible dead weight (if they are prepared on thermal acid), do not increase the concentration (only small amounts of nutrients are locally applied) and osmotic pressure of the soil solution. At the same time, both ions (ammonium and phosphate) are readily available to plants.

Potassium nitrate, KNO_3, also belongs to compound fertilizers. It contains about 13% N and up to 45% K_2O. One centner of potassium nitrate is equivalent to the same amount of potassic salt and almost 0.4 centner of ammonium nitrate. KNO_3 does not contain any dead weight and exhibits excellent physical properties. As a source of potassium, it is especially valuable for crops sensitive to chlorine.

A disadvantage of potassium nitrate is its wide nitrogen to potassium ratio (1 : 3.5), which is why it must be applied with addition of nitrogen fertilizers and, of course, phosphorus ones if all the three basic nutrients are to be supplied at a time.

Phosphomagnesia, $MgNH_4PO_4 \cdot H_2O$, or magnesium-ammonium phosphate is a sparingly soluble compound fertilizer containing 8% N and 40% P_2O_5. The ammonium of this fertilizer is nitrified in the soil as quickly as ammonium sulphate or nitrate. It can be used for basal application without harming crops even at high rates. Such micronutrients as manganese, copper, and zinc may also be added to this salt. In that case, it will be not only a nitrogen-phosphorus but also micronutrient fertilizer. Phosphomagnesia is ideally suited for use in greenhouses (hydroponics), which has been corroborated by experiments at the agricultural chemistry department of the Timiryazev Agricultural Academy in Moscow.

Nitrophoskas. Way back in 1908, Pryanishnikov suggested that in fertilizer production phosphorites should be treated with nitric rather than sulphuric acid, which, in his opinion, would yield two valuable products: nitrogen and phosphorus fertilizers.

Exposure of phosphate rocks to nitric acid gives calcium nitrate and monocalcium phosphate with a small amount of precipitate (dicalcium phosphate). This mixture, however, is not yet a good fertilizer because the absorption of water vapour by calcium nitrate increases its moisture content and its drillability becomes poor. Therefore, it requires further processing so as to transfer nitrogen from calcium nitrate into other compounds. There are several techniques of this processing.

1. Ammonium sulphate is added to the resulting mixture, or pulp, while it is still hot and pasty (which promotes the

reaction). It reacts with calcium nitrate, yielding ammonium nitrate and anhydrous calcium sulphate:

$$Ca(NO_3)_2 + (NH_4)_2SO_4 = 2NH_4NO_3 + CaSO_4$$
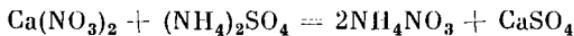
At this step of the process, if a ternary fertilizer is to be produced, a specified amount of potassium chloride is added to the pulp. It partially reacts with ammonium nitrate to yield ammonium chloride and potassium nitrate:

$$KCl + HN_4NO_3 = NH_4Cl + KNO_3$$

The pulp is then dried and granulated. Each granule contains $CaHPO_4·2H_2O$, $Ca(H_2PO_4)_2·H_2O$, NH_4NO_3, NH_4Cl, KCl, KNO_3, $CaSO_4$, and the impurities that were present in the phosphate rock. This fertilizer is known as *sulphate nitrophoska*. It has excellent physical properties and can be used in different ways to treat most crops on all soils.

2. Addition of ammonia and sulphuric acid to the pulp produces the same result as that of ammonium sulphate. However, by virtue of local alkalification of the medium, ammonia may cause partial retrogradation of the newly formed available phosphates. To avoid this, a small amount of a soluble magnesium salt is added at the same time. Addition of potassium chloride permits producing a fertilizer closely similar in composition and properties to sulphate nitrophoska, called *sulphuric acid nitrophoska* for distinction.

The use of sulphuric acid adds to the cost of nitrophoska production. One of the merits of nitric acid treatment of phosphate rock is precisely that it minimizes or even eliminates the need for sulphuric acid. Nitric acid is derived through oxidation of ammonia synthesized from atmospheric nitrogen.

3. The most advanced technique is to add phosphoric acid also to the ammoniacal pulp with the result that calcium nitrate is converted into mono- and dicalcium phosphates and ammonium nitrate, the process yielding ammophos as well:

$$3H_2O + 2Ca(NO_3)_2 + 4H_3PO_4 + 5NH_3 = 4NH_4NO_3 +$$
$$+ CaHPO_4·2H_2O + Ca(H_2PO_4)_2·H_2O + NH_4H_2PO_4$$
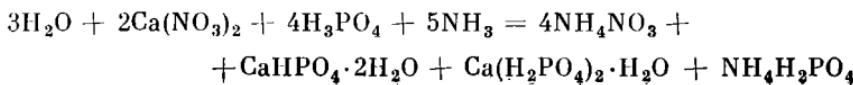
This particular nitrophoska has the highest content of water-soluble phosphoric acid (up to 80%) as opposed to the two previous ones where phosphoric acid constitutes 55 per cent of the available amount.

Introduction of potassium chloride also yields NH_4Cl and KNO_3. The soluble calcium phosphates present in the pulp together with the phosphate rock impurities will become constituents of the produced fertilizer known as *phosphoric nitrophoska*.

Nitrophoskas come in grain sizes ranging from 1 to 4 mm. The granules are quite strong and, if treated with small amounts of mineral oils and powdered with kieselguhr, talc, or finely divided limestone, do not cake in transportation and storage. The specific weight of nitrophoska is 1.0.

Nitrophoskas are usually more effective than mixed fertilizers with equal amounts of NPK.

In a series of experiments on soddy podsolic soil, the nitrogen, phosphorus, and potassium from nitrophoskas were found to be more readily available to plants than those from superphosphate mixed with ammonium nitrate and potassium chloride. This can be attributed to the more even distribution of compound fertilizer granules in the soil. It was also established that the phosphates from nitrophoskas are less susceptible to retrogradation, as compared to those of superphosphate. Another finding was a better develop-

Table 2.2. Characteristics of Nitrophosphates

Nitrophosphate	Percentage content of			Ratio of watersoluble P_2O_5 to available one (%, minimum)
	N	P_2O_5 (available)	K_2O	
Nitrophos, grade A	23.5	17	—	50
Nitrophos, grade C	24	14	—	50
Nitrophoska, grade A (16 : 16 : 13)	16-17	16-17	13-14	55
Nitrophoska, grade B (13 : 16 : 13)	12.5-13.5	8.5-9.5	12.5-13.5	55
Nitrophoska, grade C (12 : 12 : 12)	11-12	10-11	11-12	55

ment of the root system of winter wheat with an expansion
of its nitrophoska adsorbing surface, which eventually led
to higher yields of the crop. The roots of the Mironovskaya
808 winter wheat increased in weight, after treatment with
chlorine-free nitrophoska, by 33 per cent, while the weight in-
crease on the control plot was by 13.7 per cent, the increase
in root and root hair lengths being by 23.3 and 17.9 per
cent, respectively. The adsorbing working surface of winter
wheat roots at the flowering stage was 0.30 m² in control
plants and 0.79 m² per gram of dry roots after treatment
with chlorine-free nitrophoska. For characteristics of nitro-
phosphates see Table 2.2.

2.2 Fertilizers Based on Ammonium Phosphates

Compound fertilizers based on ammonium phosphates are
produced by neutralizing phosphoric and nitric acids with
ammonia. They are characterized by high contents of nu-
trients (50-70%) and water-soluble phosphorus (90-100%).

Nitroammophos is a compound fertilizer based on
monoammonium phosphate; addition of potassium makes it
nitroammophoska. Diammonium phosphate forms the basis
of *diammonitrophos* and *diammonitrophoska*, respectively.
Compound fertilizers with different ratios between nitrogen,
phosphorus, and potassium can be produced (Table 2.3).

Carboammophoska contains nitrogen in amide and ammo-
niacal forms, phosphorus which is all water-soluble, and
potassium.

It is produced from urea, phosphoric acid, ammonia,
and potassic salts (20% N, 20% P_2O_5, 20% K_2O). Carboam-
mophoska may have the following ratios of nitrogen to
phosphorus and potassium: $1:1:1$, $1.5:1:1$, $2:1:1$,
and $1:1.5:1$.

When no potassium is added, the product is known as
carboammophos containing nutrients in an amount of up to
60 per cent (30% N and 30% P_2O_5). The nitrogen to phospho-
rus ratio may be the same as in carboammophoska.

Nitroammophosphates, compound fertilizers produced
from ammophos, and carboammophosphates (Table 2.4) are
granulated (the granule size ranges from 1 to 3 mm).

Table 2.3. Characteristics of Compound Fertilizers

| Fertilizer | Percentage nutrient content | | | Nutrient ratio |
	N	P_2O_5 (available)	K_2O	
Nitroammophoska	17.5	17.5	17.5	1 : 1 : 1
	18	15	18	1 : 0.8 : 1
	15	15	23	1 : 1 : 1.5
	13	19.5	19.5	1 : 1.5 : 1.5
	13	26	13	1 : 2 : 1
	10.5	21	21	1 : 2 : 2
	17	17	17	1 : 1 : 1
	17.5	14.2	17.7	1 : 0.8 : 1
	20.5	20.5	10.2	1 : 1 : 0.5
	14.8	14.8	22.2	1 : 1 : 1.5
	18	15	18	1 : 0.8 : 1
	11.5	23	23	1 : 2 : 2
	15	22.5	15	1 : 1.5 : 1
	14	21	21	1 : 1.5 : 1.5
	13.5	27	13.5	1 : 2 : 1
	12	18	24	1 : 1.5 : 2
	17.5	17.5	17.5	1 : 1 : 1
Diammonitrophoska	15.5	15.5	23.4	1 : 1 : 1.5
	14.7	22	22	1 : 1.5 : 1.5
	21.3	21.3	10.7	1 : 1 : 0.5
	16.9	25.2	16.9	1 : 1.5 : 1
	14.4	35.7	11.4	1 : 2.5 : 1
	12	24	24	1 : 2 : 2

Table 2.4. NPK Content in Compound Fertilizers Based on Ammonium Phosphates (%)

Fertilizer	N	P_2O_5	K_2O
Nitroammophos:			
grade A (1 : 1)	23	23	—
grade B (1 : 1.5)	16	24	—
Nitroammophoska, grade I (total NPK: 50%)	16	16	18
Nitroammophoska, grade II (total NPK: 44%)	14	14	16
Carboammophos	30	30	—
Carboammophoska, grade I (total NPK: 60%)	20	20	20

Urea Phosphates. Urea phosphate forms in the reaction between thermal phosphoric acid and synthetic urea. Its production relies on the capacity of the latter to form complexes with phosphoric acid. Ammonia and potassium chloride may be added. The fertilizer contains up to 36% N, up to 48% P_2O_5, or 24% N and 24% P_2O_5.

Amides of Phosphorus are high-analysis fertilizers in which the total content of nitrogen and phosphorus may reach 120 to 147 per cent, which is almost twice as high as in ammophoska and diammophoska.

Phosphoric anhydride is a promising source of amides, imides of phosphoric acid, and dehydrated ammonium phosphates slowly soluble in water, not leachable or fixable in the soil.

A reaction between P_2O_5 and NH_3 yields a mixture of nitrogen-phosphorus compounds of various compositions: diamidopyrophosphoric acid $P_2O_3(NH_2)_2(OH)_2$, diammonium monoamidopyrophosphate $P_2O_3(NH_4)_2(NH_2)(OH)$, or an ammonium salt of such a polyphosphoric acid in which the phosphorus atoms are linked not only via oxygen ones but also by imido groups (NH).

Phosphonitrile amide contains 93% P_2O_5 and 54% N, whereas triamide of orthophosphoric acid contains 75% P_2O_5 and 44% N. This fertilizer is almost as effective as ammonium nitrate and monoammonium phosphate.

Treatment of apatite with sulphuric acid in the presence of potassium chloride gives phosphorus-potassium fertilizers, including *superphoska* and *high-analysis superphoska.*

Depending on the grade, superphoska may contain 11 to 16 per cent of available phosphoric acid, while high-analysis superphoska contains 18 to 27% available phosphoric acid, 12 to 21% K_2O in grade I and 23-33% K_2O in grade II. The free acid content does not exceed five per cent, and the moisture content in these fertilizers is 13 to 14 per cent. They are produced in powdered form.

Compound fertilizers also include *ammoniated superphosphate.* It is produced by saturating ordinary superphosphate with ammonia. This is done to neutralize its free acidity and, at the same time, reduce its hygroscopicity, whereby the physical properties of the fertilizer are improved. It is

more readily miscible with other fertilizers and exhibits better drillability.

As it combines with free phosphoric acid, ammonia forms ammophos. However, if more ammonia is added than is necessary for neutralization, phosphoric acid starts undergoing retrogradation to form tricalcium phosphate. This is undesirable because phosphorus may become unavailable. Ordinary powdered superphosphate is capable of absorbing up to six per cent of ammonia nitrogen, yet, to avoid retrogradation of monocalcium phosphate, it is added in an amount not exceeding three or four per cent.

The nitrogen of ammoniated superphosphate is readily taken up by all crops, but its amount is too small for improving the nitrogen nutrition of plants. Therefore, ammoniated superphosphate is drilled at seeding when the nitrogen supply must be restricted. In the case of basal application, such superphosphate must be used together with prescribed amounts of nitrogen fertilizers.

2.3 Polyphosphates

Polyphosphates are highly concentrated multiple fertilizers differing qualitatively from standard forms of currently produced fertilizers in the specific structure of the phosphate component. The high-energy $P-O-P$ bonding that holds together the chains and rings of the polyphosphate anion is the predominant factor determining the effect of these fertilizers on some physicobiochemical processes in plants.

The capacity of plant roots and soil microflora cells to hydrolize $P-O-P$ bonds as well as the ability of plants to partially take up phosphorus with a non-hydrolyzed $P-O-P$ bond seem to be responsible for the specific physiological effect of these fertilizers. The polyphosphate hydrolysis reaction proceeds as follows:

$$2HPO_3 + H_2O \rightarrow H_4P_2O_7; \quad H_4P_2O_7 + H_2O \rightarrow 2H_3PO_4;$$
$$H_5P_3O_{10} + 2H_2O \rightarrow 3H_3PO_4; \text{ and so on}$$
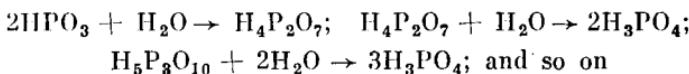
At 7 to 12 °C, hydrolysis proceeds slowly, its rate increasing at 12 to 15 °C. It depends on soil types; biologically active soils promote this process. The optimal temperature range for hydrolysis is 30 to 35 °C.

Until recently, the technology underlying the production of high-analysis superphosphate, precipitate, and ammonium phosphates involved exclusively orthophosphoric acid (H_3PO_4) which in its purest form may contain not more than 54% P_2O_5. At the same time, the currently produced blends of polyphosphoric acids contain 70 and even more per cent (up to 83%) of P_2O_5. This permits producing even more concentrated compound fertilizers.

The production of polyphosphoric acids requires heating and vacuum:

$$2H_3PO_4 \xrightarrow[\text{heating}]{\text{vacuum}} H_4P_2O_7 + H_2O;$$

$$H_3PO_4 + H_4P_2O_7 \xrightarrow[\text{heating}]{\text{vacuum}} H_5P_3O_{11} + H_2O;$$

$$H_5P_3O_{10} \xrightarrow[\text{heating}]{\text{vacuum}} 3HPO_3 + H_2O; \text{ and so on}$$
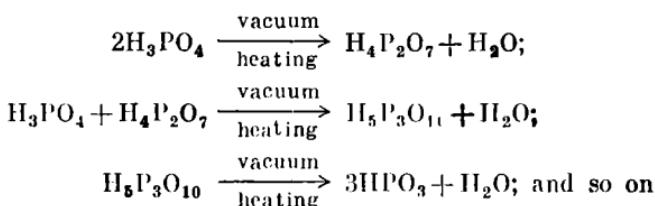
These reactions involve condensation (compaction of phosphoric acid molecules with liberation of water), therefore, polyphosphoric acids are also referred to as condensed.

Some polyphosphoric acids may be termed in the following manner: metaphosphoric, HPO_3; pyrophosphoric, $H_4P_2O_7$; tripolyphosphoric, $H_5P_3O_{10}$; tetrapolyphosphoric, $H_6P_4O_{13}$; and so forth. The maximum P_2O_5 concentration attained so far in a blend of polyphosphoric acids is 83 per cent.

Polyphosphoric acids are transported in tank cars and trucks, the tanks being made of natural or butyl rubber, neoprene, or stainless steel. The first polyphosphates in the Soviet Union were produced in 1964.

Polyphosphates (general formula: $H_{n+2}P_nO_{3n+1}$) are essentially linear polymers containing hundreds of PO_4 groups. There are also ultrapolymers of this type, which contain thousands of such groups.

The starting material in the production of polyphosphates is a blend of polyphosphoric acids obtained from concentrated orthophosphoric acid obtained by way of extraction or from elemental phosphorus produced thermally.

Granulated ammonium phosphates (15-62-0) are produced by ammoniation of thermal superphosphoric acid (76-77% P_2O_5) in pressure reactors. The melt is granulated, cooled,

and screened. These fertilizers are used in the solid form or as the basic ingredient of liquid and suspension fertilizers, owing to their good solubility.

The structural features of polyphosphates permit several inorganic nutrients (nitrogen, potassium, calcium), including micronutrients, to be incorporated into them. This opens up wide possibilities in the research aimed at developing new types and forms of such fertilizers.

The specific structure of polyphosphates substantially affects the phosphorus regime in the soil and to a great extent determines their agronomic effectiveness depending on the type of soils to which they are applied.

Owing to the possibility of incorporating micronutrients directly into polyphosphate molecules, these fertilizers may become extremely valuable. According to experimental data, incorporation of zinc into triammonium polyphosphate increased the yield of flax seeds by 18 per cent. Zinc incorporated into ammonium orthophosphate provided for even a greater increase in seed yield. Addition of manganese to tripotassium polyphosphate considerably enhanced the effectiveness of this fertilizer: the biological yield of fibre flax increased (in comparison with Mn-free fertilizers) by 24 per cent, the yield of flax seeds by 29 per cent, and that of straw, by 22 per cent. Without manganese, yield increases were 14, 14, and 15 per cent, respectively.

In greenhouse experiments with maize grown on calcareous sierozem, its yield increased from 12.2 g (after application of tripotassium polyphosphate) to 17 g per pot in the case of tripotassium polyphosphate with zinc.

The availability of polyphosphates to plants depends on the extent of their hydrolysis in the soil. This process is affected by the temperature, biological activity, pH, and mineralogical composition of the soil.

It takes more time for polyphosphates, as opposed to orthophosphates, to form insoluble compounds with iron, aluminium, and manganese in the soil. They readily react with calcium and magnesium to form ammonium-containing complexes (primarily pyrophosphates), which are adequate sources of nitrogen and phosphorus for plants. Polyphosphates are less mobile in the soil than orthophosphates because they react more actively with soil minerals, however,

their mobility is largely dependent on soil properties rather than the phosphate form.

Polyphosphates exhibit the same properties as cation exchangers: they are capable of adsorbing calcium and other cations in exchange to NH_4 and H^+. The chemical properties of polyphosphates are so similar that they can be identified only by chromatographic separation.

Pyro- and tripolyphosphates dissolve iron and aluminium compounds in the soil, thereby preventing deposition of these cations in the form of orthophosphates. Reactions of pyrophosphates with calcium and magnesium yield salts easily available to plants. Sterilization of the soil sharply reduced the rate of triammonium pyrophosphate hydrolysis in different soils. There is evidence supporting the greater mobility of tripolyphosphates as opposed to ortho- and pyrophosphates.

Worthy of mention among compound fertilizers are *ammonium polyphosphates* containing up to 15% N and 60% P_2O_5. By virtue of their high effectiveness, ammonium polyphosphates may find application in Central Asia and Kazakhstan with their calcareous soils, in Kuban, in Moldavia, and in southern parts of the Ukraine.

Solid ammonium polyphosphates have proved their worth in the production of mixed fertilizers. For example, addition of ammonium nitrate and potassium chloride to them gives a ternary fertilizer containing 12% N, 24% P_2O_5, and 24% K_2O. By incorporating urea and potassium chloride into ammonium polyphosphate it is possible to obtain a fertilizer containing each of these nutrients in an amount of 20 per cent.

Potassium Metaphosphate. In perennial experiments with potatoes and sugar beet grown on soddy podsolic sandy loam, potassium metaphosphate increased the yield of these crops and improved their quality to a greater extent than equivalent amounts of nutrients in single fertilizers. When scattered over soddy podsolic loam and applied locally to potatoes and barley (against the regular background of nitrogen), potassium metaphosphate increased their yields similarly to superphosphate with potassium chloride.

Notably, this applies to the poorly soluble finely crystalline $(KPO_3)_n$. The contents of P_2O_5 and K_2O in crops were

4*

approximately equal. In experiments with fibre flax, phosphorus was taken up at the same rate from both metaphosphate and superphosphate, while the potassium uptake rate was higher in the case of KCl.

On deep chernozem (Kharkov Region), potassium metaphosphate approached mixtures of superphosphate and potassium chloride in terms of its effect on sugar beet and wheat.

2.4 Liquid and Suspension Fertilizers

Liquid compound fertilizers (LCF) include solutions of nutrient salts containing two or three primary nutrients (N, P, K), secondary nutrients (Ca, Mg, S), and micronutrients (Fe, Mn, B, Cu, Zn, Mo, Co, Cl).

Experiments have shown that solid and liquid compound fertilizers produce almost the same effect on crops. LCF based on polyphosphoric acid have been found to be slightly more effective on calcareous and other base-saturated soils. The effectiveness of LCF on acid (red and soddy podsolic) soils increases when they are applied locally.

LCF are considered to be among the most promising forms of mineral fertilizers.

The process in which LCF are produced boils down to neutralization of phosphoric acid (obtained by extraction or thermally) with ammonia to pH 6.5. Depending on the process, the neutralizing agent is either aqua or anhydrous ammonia. There are two types of LCF distinguished according to the form of the phosphorus used in their production, those based on orthophosphoric acid and superphosphoric acid (the latter is essentially a blend of ortho- and polyphosphoric acids, containing 72-80% P_2O_5). The nitrogen content in LCF is increased by adding ammonium nitrate, urea, or a mixture of urea and ammonium nitrate.

The LCF based on thermal orthophosphoric acid are almost transparent liquids, while those based on orthophosphoric acid produced by extraction are turbid solutions (as a result of formation of such disperse particles as ammoniated aluminium and iron phosphates and silicic acid). The concentration of nitrogen-phosphorus LCF based on superphosphoric acid is much higher than that of the orthophosphate-

based ones (Table 2.5). Polyphosphates also emulsify the impurities precipitating during ammoniation of the phosphoric acid produced by extraction, and addition of small amounts of superphosphoric acid (20% in the case of potas-

Table 2.5. $N : P_2O_5 : K_2O$ Ratio in Liquid Fertilizers Based on Orthophosphoric and Superphosphoric Acids

$N : P_2O_5 : K_2O$	Orthophosphoric acid	Superphosphoric acid
4 : 1 : 0	16-4-0	24-6-0
3 : 1 : 0	18-60	24-8-0
2 : 1 : 0	16-8-0	22-11-0
1 : 1 : 0	13-13-0	19-19-0
1 : 2 : 0	9-18-0	15-30-0
1 : 3 : 0	8-24-0	12-36-0

Note: The additional component of LCF is a mixture of urea and ammonium nitrate

sium-free LCF and 30% in the case of potassium-containing LCF) clarifies LCF based on orthophosphoric acid obtained by extraction.

Production of Ternary Liquid Fertilizers. Ternary liquid fertilizers are produced either by hot or cold mixing.

1. In the hot mixing process, phosphoric and polyphosphoric acids are neutralized with gaseous and aqua ammonia with addition of other starting components which dissolve in the resulting mixture. The nitrogenous and potassic components are usually in the form of a urea-ammonium nitrate solution of grade 28-0-0 or 32-0-0 and potassium chloride.

2. The cold process involves mechanical mixing of prepared solutions of the starting components. Used in cold mixing are solutions of ammonium phosphates and solid diammonium phosphate. The nitrogenous and potassic components are the same as in the hot process.

Cold-Mixed Liquid Fertilizers. The most widely used are mixtures of ammonium polyphosphate of grade 10-34-0 or 11-37-0 with urea-ammonium nitrate (28.3 or 32% N) and potassium solutions. All the ingredients are fed into a mixing chamber. Since no cooling is required, the expenses

involved in the cold process are half as high as in the hot one.

Solid ammonium polyphosphate, grade 15-62-0, may also be used in the production of liquid fertilizers. It has to be ammoniated to the desired pH in the course of mixing.

Additional nitrogen is introduced into various grades of LCF in the form of urea, ammonium nitrate, or a mixture of both.

Urea and ammonium nitrate solutions can be obtained by mixing solid granulated products with water. It is much cheaper, however, to produce them directly at plants.

Most of polyphosphoric acids are currently used in the production of LCF. The solubility of ammoniated thermal acids at 0 °C depends on the degree of ammoniation and concentration. About half the phosphorus in a solution of polyphosphoric acids containing 76% P_2O_5 is in the form of polyphosphates; they keep on dissolving until the nutrient concentration passes the 46 per cent mark. The composition of such a solution (%) is 10-34-0 (N:P_2O = 0.30). When acids containing 78-80% P_2O_5 are used, the solutions have the composition 11-37-0 (N:P_2O = 0.30).

Polyphosphates are hydrolyzed in solution to orthophosphates, the hydrolysis rate being negligible at low temperatures and increasing with heating. Prolonged storage in hot weather intensifies hydrolysis. When fertilizer 10-34-0 containing a large amount of magnesium is stored for a long period of time, crystalline magnesium-ammonium polyphosphate, $(NH_4)_2MgP_2O_7 \cdot 4H_2O$, may precipitate, its crystals growing at a fast rate. Addition of 20% P_2O_5 in the form of an 11-37-0 solution slows down crystallization and prolongs the shelf life of the fertilizer from five weeks to three months.

LCF based on phosphoric acid have a relatively low total nutrient content (24-30%) because in more concentrated solutions salts tend to crystallize at low temperatures and precipitate.

In the USSR, liquid fertilizers with 9:9:9, 7:14:2, 6:18:6, 8:24:0, and other ratios are also produced.

Polyphosphoric acid forms the basis of LCF with a nutrient content exceeding 40 per cent. The basic solutions of such LCF have compositions 10-34-0 and 11-37-0. They are used in the production of ternary LCF of various compositions with addition of urea, ammonium nitrate, and potassium

chloride. The density of these basic solutions is 1.35 to 1.4, and the crystallization temperature is -18 °C. No deterioration in long-term storage takes place (even at abrupt temperature changes).

LCF do not contain any free NH_3, therefore, they can be sprayed over the field surface with subsequent incorporation into the soil by any implements, such as disc harrow, cultivator, or plough. Special machines can be used to apply LCF locally (band application) to treat any crop, particularly a row one. They can be used in irrigated regions (with irrigation water).

LCF permit complete mechanization of all fertilizer handling operations without any losses whatsoever during transportation, reloading, storage, and application.

Other obvious advantages of LCF include ease of automatic control of their distribution over a field (even distribution leads to simultaneous development and maturation of crops, whereby crop losses are minimized) and the possibility of dissolution of herbicides, insecticides, micronutrients, and growth substances in them for joint application. Furthermore, the production of LCF requires less capital to be invested per ton of fertilizer, as compared to solid products, due to fewer operations being involved in their manufacturing process.

The economic efficiency of liquid fertilizers is beyond any doubt. The capital investments in the building of plants for LCF production are 20 to 30 per cent lower than in the case of solid fertilizers (because no drying or granulation are necessary).

Even when LCF and solid fertilizers are produced at the same cost, the former are 3 to 3.3 times cheaper in application. The major savings are achieved in their handling and transportation. The transportation and application of LCF cost two to two and a half times less than those of solid fertilizers. The available statistics attests to the high economic efficiency of LCF.[1]

LCF can be applied with the aid of the existing herbicide and aqua ammonia applicators.

However, the application of LCF calls for use of high-capacity machines. It should also be borne in mind that LCF (especially suspension fertilizers) are highly corrosive.

In the years to come, LCF may become an important and, in some regions, predominant form of fertilizers. LCF are agronomically as effective as solid fertilizers. They are particularly promising for treatment of calcareous sierozems and other soils with an alkaline reaction.

Of particular importance is to properly select the time, techniques, and rates of LCF application. The phosphorus of LCF, as opposed to solid orthophosphates, is more readily soluble in water with the result that it is more easily washed away by the surface runoff, which means that taking the relief of the ground surface into consideration is extremely important.

Suspension Fertilizers. The main difficulty encountered in the production of liquid fertilizers is the need to free the product from suspended solids because suspensions contain crystals of water-soluble salts along with particles of insoluble or poorly soluble substances.

As a result, the concentration of nutrients may by far exceed their solubility. In the case of suspended liquid fertilizers, such impurities do not matter since the suspensions are prepared with addition of colloidal clay (in amounts to obtain approximately 2% suspensions of the latter).

All suspension grades are characterized by a higher nutrient content than the similar clear liquids and, in this respect, they are comparable with solid mixtures.

To prevent crystal growth and precipitation of solids, as well as to increase the nutrient concentration in LCF, added to the latter are stabilizing substances, namely, collodial clays, which do not allow the solid phase to precipitate from the supersaturated solution.

The basic suspension fertilizer has the composition 12-40-0 and can be used as a major component of ternary LCF of different compositions (15-15-15, 10-30-10, 9-27-13, etc.). The suspension density is 1.4 to 1.5. After two or three weeks in storage, suspensions tend to get thick and segregate, which is why they must be prepared to be used within this period of time.

Special machines are required to transport and apply suspensions.

To produce suspension fertilizer 12-40-0, thermal superphosphoric acid (80% P_2O_5) is ammoniated with addition

of 3 per cent (by weight) of colloidal clay. This fertilizer lends itself to storage without deterioration over a period of three months at temperatures ranging from 0 to 27 °C, but it should be remembered that at -18 °C it solidifies. Storage at a temperature in the neighbourhood of 36 °C soon leads to hydrolysis of the fertilizer, converting it into crystalline diammonium phosphate: $(NH_4)_2HPO_4$. Addition of smaller amounts of clay inhibits the crystallization but impairs the fertilizer quality. Hence, liquid and suspension fertilizers should preferably be used while fresh, without prolonged storage.

A suspension based on solution 10-34-0, a urea-ammonium nitrate solution, dry urea, and potassium chloride has the following characteristics: composition (%) 13-13-13; density 1.427; pH 6.39; and clay content 3 per cent. When stored in sealed vessels at varying temperatures (0-30 °C) over a long period of time, the suspension undergoes segregation, but can easily be brought back to the original uniform consistency by stirring.

Addition of a larger amount of urea gives a fertilizer of composition 9-9-9 with a crystallization temperature below -18 °C.

Mixing at low temperatures yields fertilizers of composition 5-15-30 based on solution 12-40-0 and urea with ammonium nitrate. Micronutrients may be added to suspensions containing ammonium polyphosphate.

Suspension 15-15-15 prepared from ammonium polyphosphate 12-40-0 and solutions of urea with ammonium nitrate

Table 2.6. Micronutrient Content in Suspension 13-13-13

Micronutrient salt	Addition rate (kg per 60 kg P_2O_5)	Concentration in end product (%)	Suspension stability (days)
$MnSO_4$	5.0	0.975—Mn	20
$ZnSO_4$	0.5	0.108—Zn	30
$CuSO_4$	0.8	0.172—Cu	30
$Co(NO_3)_2 \cdot 6H_2O$	—	0.200—Co	30
$(NH_4)_6Mo_7O_{24} \cdot 6H_2O$	0.2	0.0432—Mo	30
H_3BO_3	0.4	0.0863—B	30
All salts	—	1.585	20

(32-0-0) and potassium is ideally suited to receive micronutrients incorporated into it in the following amounts: 0.35% B in the form of $Na_2B_4O_7 \cdot 5H_2O$, 1.20% Cu as $CuSO_4 \cdot H_2O$, 1.20% Fe in the form of $Fe_2(SO_4)_3 \cdot 9H_2O$, 0.34% Mn as $MnSO_4 \cdot nH_2O$, and 2.50% Zn in the form of $ZnSO_4$.

Added to clay suspension 13-13-13 were micronutrients, such as manganese, zinc, copper, cobalt, molybdenum, and boron, separately and jointly.

The micronutrient addition was in compliance with cropping requirements (Table 2.6).

Almost all liquid complex fertilizers and suspensions are produced in two ways: hot mixing with chemical reactions (multiple fertilizers) and cold mixing from intermediate solutions (mixed fertilizers).

2.5 Mixed Multiple Fertilizers

The compound fertilizers of this group are produced by treatment of processed fertilizers (ammophos, diammophos, etc.) with ammonia, ammoniates, and acids with subsequent granulation. These fertilizers have a more uniform grain-size distribution (granules 1 to 3.2 mm in size account for 90%).

2.6 Mixed Fertilizers

Mixed fertilizers are of two types, i.e. solid and liquid.

In terms of the processing techniques, solid mixed fertilizers fall in two categories: mechanical mixtures and mixed multiple fertilizers.

Mechanical mixing involves no perceptible reactions between the components. Mechanical mixtures are, in turn, divided into powdered and granulated ones. The latter have the advantage of being produced at any nutrient ratio.

Granulated mixed multiple fertilizers are obtained by adding ammonia and inorganic acids (H_2SO_4 and H_3PO_4) to the mixture of single fertilizers with subsequent granulation.j

The granulated mixed multiple fertilizers manufactured in the Soviet Union are products of ammoniation of a mixture of ordinary superphosphate, nitrogen salt melts (or

crystals), ammoniate, and potassic salts. Five grades of such fertilizers have been slated for production. The crushing strength of granules of all grades must be at least 2 MPa (20 kgf/cm²). Their grain-size distribution is as follows: granules 1 to 3.2 mm in size account for at least 90 per cent, 3.2 to 5 mm in size for not more than 5 per cent, and less than 1 mm in size for not more than 5 per cent.

The processing of mechanical mixtures comprises five steps:

(1) preparation of fertilizers;
(2) feeding of components into the mixer;
(3) metering;
(4) mixing;
(5) discharging of the mixture into a truck, a fertilizer tank, or a storage facility.

Table 2.7. Nutrient Content in Mixed Multiple Fertilizers of Various Grades

Grade	Percentage content of			Ratio between water-soluble and available P_2O_5 (%)
	N	P_2O_5 (available)	K_2O	
1 : 1 : 1	10-11	10-11	10-11	85
0 : 1 : 1.5	0	13-14	19-20	85
1 : 0.7 : 1	12-13	8-9	12-13	85
1 : 1 : 1.5	9-10	9-10	14-15	85
1 : 1.5 : 1	8-9	12-13	8-9	85
1 : 1.5 : 0	10-11	15-16	0	85
1 : 2 : 2	8-9	17-18	17-18	85

One of the basic requirements to be met in the production of granulated mixtures is to obtain loose, non-caking products suitable for mechanized broadcasting.

The physicochemical properties of granulated mixtures are governed by a number of factors, such as volumes to be mixed, mixing duration and technique, transportation to the field, and so on.

There are two ways in which mixed fertilizers can be used: directly after preparation and after preparation followed by storage.

The single and unbalanced fertilizers used in dry mixing must remain loose without caking and retain their grain-size distribution during transportation in special cars with bottom discharge and bulk storage for six months. The moisture content should not exceed 0.12 per cent in urea and ammonium nitrate, 1 per cent in ammophos, diammophos, and potassium chloride, 3.5 per cent in double superphosphate (not more than 1% at free acidity). Granules 1 to 3 mm in size must account for at least 90 per cent, including at least 50 per cent of granules 2 to 3 mm in size, while those smaller than 1 mm must account for not more than 1 per cent.

Not more than 3 per cent of granules are allowed to be crushed during mixing, their crushing strength being at least 2 MPa (20 kgf/cm^2).

The chemical industry offers a rather wide range of granulated and pelletized fertilizers to be mixed, including urea, ammonium nitrate, double and ordinary superphosphate, ammophos, and potassium chloride.

The physical properties of mixed fertilizers can be improved by using such neutralizing additives as chalk, limestone, and ground phosphate rock.

In the Soviet Union, standard specifications have been issued to cover two types of mixed fertilizers: MRTU 6-08-141-69 covering a mixture of powdered superphosphate with ground phosphate rock, taken at a ratio of 1 : 1, and TU 6-08-336-75 covering a binary phosphorus-potassium fertilizer produced by mixing crystalline potassium chloride with ordinary superphosphate with subsequent granulation by compression. Granules ranging in size from 1 to 4 mm account for not less than 90 per cent in this fertilizer, those 4 to 6 mm in size constitute not more than 5 per cent, and granules smaller than 1 mm constitute not more than 5 per cent. The crushing strength of these granules is 3.5 to 4.0 MPa (35 to 40 kgf/cm^2).

The physicochemical properties of the starting fertilizers often impose limitations on the possibility of their mixing.

For example, when ammonium nitrate is mixed with superphosphate, nitric acid vapour or nitrogen oxides may evolve:

$$NH_4NO_3 + H_3PO_4 \rightarrow NH_4H_2PO_4 + HNO_3$$
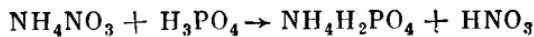
The formation of calcium nitrate makes the mixture more hygroscopic:

$$2NH_4NO_3 + Ca(H_2PO_4)_3 \rightarrow 2NH_4H_2PO_4 + Ca(NO_3)_2 + nH_2O$$

Calcium carbonate and bicarbonate, having an alkaline reaction, and metallurgical basic slags, containing free calcium oxide, cannot be mixed with ammonium nitrate or sulphate as well as with ammonium phosphates and polyphosphates because of the possible ammonia losses:

$$CaO + (NH_4)_2SO_4 \rightarrow 2NH_3 + CaSO_4 + H_2O.$$
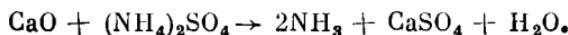
When several starting components with improved physicochemical properties are taken, one can prepare mixed fertilizers suitable for prolonged storage. For example, addition of neutralizing agents (dolomite, bone meal, or ground phosphate rock) plus ammoniated superphosphate precludes formation of nitric acid, prevents conversion of monocalcium into dicalcium phosphate, and improves the physical properties of the fertilizer.

Complete neutralization of superphosphate or reduction of the free P_2O_5 content (down to 1%) and moisture content (down to 4% in ordinary and 3% in double superphosphate) in it give, in a mixture with carbamide, a fertilizer of composition 1 : 1 : 1.

Mixtures of standard granulated ammophos with potassium chloride, neutralized superphosphates, and ammonium sulphate exhibit excellent physical properties, and the low

Limitations of Fertilizer Mixing

Ammonium nitrate	1	0									
Carbamide	2	1	1								
Ammonium sulphate	3										
Neutralized superphosphate (ordinary and double)	4	1	1	2							
Precipitate	5	1	1	2	2						
Ground phosphate rock	6	1	1	2	2	2					
Metallurgical slags	7	0	1	0	0	0	2				
Ammophos	8	1	1	2	2	2	2	0			
Potassium chloride	9	1	1	1	1	1	1	1	1		
Potassium sulphate	10	1	1	2	2	2	2	2	2	2	
	1	2	3	4	5	6	7	8	9	10	

0 — mixture properties are impaired substantially; 1 — prolonged storage impossible; 2 — mixing in advance is tolerable.

hygroscopicity of these fertilizers makes it possible to keep them in prolonged storage.

One of the important requirements to be met by mixed fertilizers is uniformity of their grain-size distribution, which is attained by close tolerances in the size of starting component granules.

2.7 Dry Mixing of Fertilizers

Dry mixing is the simplest and cheapest way to produce compound fertilizers with the desired nutrient ratio.

At present, two dry mixing procedures are predominant: (1) mixing of fertilizers at farms using stationary or mobile mixers and machines designed to prepare fertilizers during storage, transport and apply them (MVS-3M, D-665); and (2) mixing in high-capacity (40-60 t/h) stationary units supplying fertilizers to several farms through district associations "Selkhozkhimiya".

One of the chief trends in the fertilizer industry is a steady increase in the production of high-analysis single and compound fertilizers.

To improve the quality and effectiveness of compound fertilizers, a great deal of attention should be given to incorporation of magnesium and micronutrients into them with due account for differences in crops and the soils on which the latter are grown.

In view of the possibility of resolving, in the nearest future, some of the pressing problems of improvement of plant nutrition from soils, including liming of acid soils and gypsuming of alkaline ones, further research aimed at enhancing the effectiveness of compound fertilizers will involve search for radically new forms and applications with predetermined rates of nutrient release in the soil.

The availability of such fertilizers (including slow-acting ones) will stipulate development of new systems of their application in different soil and climatic zones of the country to treat all crops.

New forms of fertilizers will provide for a more complete uptake of nutrients both from fertilizers and from the soil reserves. This, of course, will not only cut down the cost of farm produce, but also prevent pollution of the environment.

Manure

Solid and liquid manure, peat, human waste, poultry manure, composts, garbage, green manure, and the like belong to organic fertilizers. Among them, manure is the main and most common organic fertilizer. All these fertilizers are referred to as local because farms usually do not bring them from outside (except for organic municipal waste); instead, they accumulate (solid and liquid manure, human waste, poultry manure), extract (peat), prepare (compost), or grow (green manure) these fertilizers locally.

Organic fertilizers produce a multiple effect on the agronomical properties of the soil and, if applied properly, drastically increase crop yields. Their primary importance stems from the fact that they serve as a source of nutrients to crops. They supply the soil with all the necessary macro- and micronutrients. For example, a ton of cattle manure in terms of dry weight contains about 20 kg of nitrogen, 8 to 10 kg of phosphorus (P_2O_5), 24 to 28 kg of potassium (K_2O), 28 kg of calcium (CaO), 6 kg of magnesium (MgO), 4 kg of sulphur (SO_3), 20 to 40 g of boron, 200 to 400 g of manganese (MnO), 20 to 30 g of copper, 125 to 200 g of zinc, 2 to 3 g of cobalt, and 2 to 2.5 g of molybdenum. These are known as complete fertilizers. The percentage content of the basic nutrients in manure, peat, and human waste (at a particular moisture content) is shown in Table 3.1.

20 tons of half-decomposed litter manure contains as much nutrients as 2.5 centners of ordinary superphosphate, 2 centners of potassium chloride, and 3 centners of ammonium nitrate. Hence, the importance of rational use of organic fertilizers in the national economy.

As opposed to inorganic fertilizers, organic ones are much less concentrated in terms of the nutrient content. In other words, if the content of nutrients in inorganic fertilizers is measured in tens of per cent, that in organic fertilizers is

Table 3.1. Nutrient Content in Some Organic Fertilizers (%)

Organic fertilizer	N	P_2O_5	K_2O	CaO
Half-decomposed manure (at a moisture content of 75%)	0.50	0.25	0.60	0.70
High peat (at a moisture content of 60%)	0.35	0.03	0.03	0.04
Low peat (at a moisture content of 60%)	1.05	0.14	0.07	0.14
Human waste	0.67	0.33	0.20	0.10

measurable in fractions of a per cent and, in a few cases, one or two per cent. This is why the rates of application of these two groups of fertilizers differ widely when the same amount of the active ingredient has to be incorporated into the soil. If inorganic fertilizer rates amount to centners per hectare, organic fertilizers must be applied at rates equal to tons and even tens of tons. Organic fertilizers are difficult to transport, therefore, they should preferably be used in nearby fields and plots.

Application of organic fertilizers, just as inorganic ones, is a major intervention of man into the nutrient cycle in agriculture. Incorporation of solid and liquid manure, poultry manure, and human waste is essentially partial reutilization of the nutrients that had previously been taken up by crops and contributed to their yield. Manure, for example, receives through animal feed such nutrients as nitrogen, phosphorus, potassium, and others previously taken up by plants. Obviously, part of the nutrients from the inorganic fertilizers applied to the soil eventually find their way into manure via animal feed and litter, then return into the soil when fields are manured.

The nutrient cycle in agriculture entrains a large quantity of atmospheric nitrogen fixed by the nodule bacteria of legumes. When animals are fed with legumes, most of the nitrogen fixed by them finds itself in manure. Thus, with extensive application of inorganic fertilizers and cultivation of leguminous crops, manure serves as a source of increasing amounts of nitrogen, phosphorus, and potassium used in farming.

Application of some other organic fertilizers, such as peat, municipal waste (garbage), and freshwater silt, means involvement of new extrinsic nutrients in the cycle.

Cultivation of leguminous crops as green manure is conducive to large amounts of atmospheric nitrogen becoming entrained in the nutrient cycle.

Manure and other organic fertilizers supply crops not only with inorganic nutrients, but also with carbon dioxide. When decomposed in the soil, these fertilizers release a lot of carbon dioxide which saturates the soil air and the surface layer of the atmosphere with the result that the aeration of plants is enhanced. The higher the rates of the manure or peat composts applied to the soil, the greater the amount of carbon dioxide forming in their decomposition and the more favourable the conditions for air supply to plants. When 30 to 40 tons of manure are incorporated into the soil, the daily amount of the carbon dioxide released during its intensive decomposition increases by 100 to 200 kg/ha as compared to the plot that has not received any manure. The importance of such a CO_2 release rate can be seen from the statistics showing that to obtain a 20 to 25 cent/ha yield of cereals requires about 100 kg of carbon dioxide, while the yield of potatoes and vegetables equal to 40 to 50 t/ha requires 200 to 300 kg of CO_2.

Organic fertilizers supply energy and food to soil microorganisms. Moreover, such organic fertilizers as manure and human waste are themselves rich in microflora and add a variety of microorganisms to the soil. As a result, manure and some other organic fertilizers activate nitrogen-fixing bacteria, ammonifiers, nitrifiers, and other groups of microorganisms.

In humus-deficient and poorly cultivated soddy podsolic soils, organic fertilizers not only sustain root and aerial nutrition of plants, but also drastically improve the soil properties. Systematic heavy application of organic fertilizers improves the agrochemical properties of soils, whereby they become richer in humus, display better biological, chemical, physical, and physicochemical properties as well as air and water regimes. Increasing among other things are the exchange capacity and base (Ca, Mg, K) saturation of the soil, whereas its acidity (if the soil is acidic) decreases

slightly along with the mobility of aluminium, iron, and manganese in it, and the buffering capacity of the soil becomes more pronounced. Under the effect of organic fertilizers, heavy soils become less tenaceous, while light soils acquire higher moisture and exchange capacities.

Application of organic fertilizers, especially in combination with inorganic ones, creates favourable conditions for high and stable yields of various farm crops.

Manure and fertilizer nutrients applied in the same amounts are usually equivalent insofar as their effect on crop yields is concerned.

High crop yields can be attained by using only inorganic or only organic fertilizers. Nonetheless, if they are properly combined, the specific limitations of each are obviated so that they can be used most rationally.

It should be borne in mind that most of the nutrients present in organic fertilizers, including manure, become available to plants only when mineralized. Therefore, by using organic fertilizers alone it is difficult to satisfy the nutrient requirements of crops, particularly at early stages of the vegetation period and during the most intensive uptake of nutrients by them.

In contrast with organic fertilizers, most inorganic ones are quick-acting. The nutrients they contain can be taken up by plants as soon as these fertilizers have been incorporated into the soil.

By using inorganic fertilizers it is easier to meet the changing nutrient requirements of crops throughout the vegetation period. For instance, starter application of inorganic fertilizers (primarily pelletized superphosphate) sustains the nutrition of crops at the earliest stage of growth, while dressing with inorganic fertilizers in addition to the organic and inorganic ones applied before sowing meets the demand of crops in nutrients more fully in the period of their maximal uptake, the available nutrients being supplied in appropriate ratios.

When only organic fertilizers are used, their nutrient ratio may differ from what is required for normal growth and development of plants. Application of mineral fertilizers alone or in combination with organic fertilizers may provide for any nutrient ratio as required by crops.

However, application of inorganic fertilizers alone often adversely affects some soil properties. For example, systematic application of physiologically acidic fertilizers to soddy podsolic soils increases their acidity and mobile aluminium content and also intensifies the chemical fixation of phosphates. Whereas organic fertilizers, as has already been mentioned above, increase the buffering capacity of the soil and decrease mobility of iron and aluminium, while superphosphate phosphorus is fixed to a lesser extent.

Using inorganic fertilizers alone increases the probability of the soil solution attaining a toxic concentration, as compared to using a combination of inorganic and organic fertilizers. This is most likely to occur in light soils with a low buffering capacity, receiving high rates of inorganic fertilizers. Such crops as cucumbers and maize are especially sensitive to high soil solution concentrations, particularly early in the vegetation period. Joint application of inorganic and organic fertilizers to these crops is much better than application of inorganic fertilizers alone.

The use of organic fertilizers permits the rates of inorganic ones to be considerably reduced, thereby precluding excessive salt concentrations in the soil solution.

As shown by experiments carried out at the USSR Research Institute of Fertilizers and Agronomical Soil Science with potatoes grown on cultivated soddy podsolic soil, when inorganic fertilizers are applied together with manure, their effect is not merely added up but is mutually enhanced (Fig. 3.1).

By saying that organic and inorganic fertilizers must be correctly combined we do not mean that they have to be incorporated together. In practical farming, it is more advisable to apply manure or another organic fertilizer to a fallow crop, while inorganic fertilizers should be applied to winter crops following the fallow crop, or organic fertilizers should be applied to row crops, followed by inorganic ones applied alone to the subsequent crops.

Manure is nothing but stable or barnyard waste primarily in the form of animal excreta. Depending on the animal farming conditions, manure may also include litter. Accordingly, distinction is made between ordinary manure with

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litter (litter manure) and semiliquid (or liquid) manure without litter.

Litter manure consists of solid and liquid animal excreta plus the litter. It contains an average of 25 per cent of dry matter and about 75 per cent of water.

Semiliquid manure without litter comprises mainly solid and liquid animal excreta and large amounts of water. It
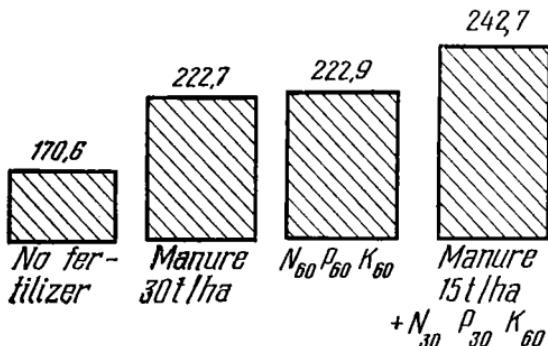

Fig. 3.1. Potato tuber yield (cent/ha) averaged over three years, as a function of manuring and inorganic fertilizer application

contains 10 to 11 per cent of dry matter and 89 to 90 per cent of water. Some of the water present in manure without litter comes as processing waste. In certain cases, water is added expressly to facilitate the removal of manure from the barn (hydraulic removal), which sharply reduces the dry matter content in it. This manure is referred to as liquid.

At large animal farms, cattle are kept without litter, hence semiliquid and liquid manure without litter is obtained.

3.1 Litter Manure

Solid and liquid animal excreta form part of manure of any consistency. On the average, about 40 per cent of organic matter, 80 per cent of phosphorus, 50 per cent of nitrogen, and 95 per cent of potassium pass from animal feed into manure. However, depending on the cattle species and age as well as the feed formula, the relative amount of the substances passing into manure varies widely. These factors

also influence the ratio between solid and liquid excreta and their nutrient content. For example, the more water the feed contains, the more liquid is excreted. The more easily digested the feed, the less dry matter is contained in solid excreta and the more in liquid ones. The more concentrated the feed given to animals and the richer it is in protein, the more nitrogen and phosphorus the manure contains. All other things being equal, the growing organism of young cattle retains much more nitrogen and phosphorus (which means that these nutrients pass into manure in much smaller amounts) than that of adults.

Solid and liquid animal excreta differ in composition and fertilizing value. Almost all of the phosphorus excreted by animals appears in solid excreta, its amount in liquid excreta being negligible. About one half to two thirds of nitrogen and almost all of potassium of the feed are excreted by animals with urine. Almost one third to one half of nitrogen and only an insignificant amount of potassium come out with solid excreta.

The nitrogen and phosphorus of solid animal excreta form part of organic compounds and become available to plants only after their mineralization, while potassium is in a mobile form. All nutrients in liquid excreta are in a readily soluble or easily mineralizable form.

Solid animal excreta are extremely rich in microorganisms, whereas urine does not contain them during excretion; it receives them later from the solid excreta.

The daily amounts and ratios of solid and liquid excreta from an animal, irrespective of its species, are dissimilar (Table 3.2).

Horses, sheep, and cattle produce more solid than liquid excreta; in the case of pigs, on the contrary, liquid excreta are twice as much in weight as solid ones. Besides, solid and liquid excreta of cattle and pigs contain less dry matter than those of sheep and horses. At the same time, solid and liquid excreta of cattle contain much less nitrogen, phosphorus, and potassium than the excreta of other animals (Table 3.3).

All these factors are responsible for the dissimilar degree of decomposition of the manure of different animals. By virtue of the higher content of dry matter, nitrogen, phospho

Table 3.2. Daily Amounts and Ratios of Solid and Liquid Excreta from an Animal

Animal	Daily amounts (kg) of		Ratio between solid and liquid excreta
	solid excreta	liquid excreta	
Cattle	20-30	10-15	2.0
Horses	15-20	4-6	3.5
Sheep	1.5-2.5	0.6-1.0	2.5
Pigs	1.5-2.2	2.5-4.5	0.5

rus, and other elements in feces and urine, the manure of horses and sheep takes less time to decompose in storage with great amounts of heat being released in the process. Such manure is referred to as *hot*. On the other hand, the manure of cattle (containing more water and smaller amounts of the basic nutrients) and pigs (containing much water and less fecal matter) decomposes slowly with a slight rise in temperature. Such manure is known as *cold*.

Litter is a constituent of litter manure. When added to the former two components, it increases the yield of manure, improves its quality, and minimizes nitrogen and liquid losses. A variety of materials are used as litter, including straw, peat, sawdust, and so on. Straw litter produces

Table 3.3. Content of Dry Matter, Nitrogen, and Ash Elements (%) in the Excreta of Various Animals

Animals	Dry matter	N	P_2O_5	K_2O	CaO	Mg	SO_4
			In solid excreta				
Cattle	16	0.29	0.17	0.10	0.35	0.13	0.04
Horses	24	0.44	0.35	0.35	0.15	0.12	0.06
Sheep	35	0.55	0.31	0.15	0.46	0.15	0.14
Pigs	18	0.60	0.41	0.26	0.09	0.10	0.04
			In liquid excreta				
Cattle	6	0.58	0.01	0.49	0.01	0.04	0.13
Horses	10	1.55	0.01	1.50	0.45	0.24	0.06
Sheep	13	1.95	0.01	2.26	0.16	0.34	0.30
Pigs	3	0.43	0.07	0.83	0.01	0.08	0.08

straw manure, and when litter is of peat, we have peat manure.

Litter is of great zoohygienic and agronomical importance. It provides a soft dry bedding for animals and increases the yield of manure. Manure receives with litter additional amounts of nutrients which are transformed in microbiological processes to more readily available forms (Table 3.4).

Table 3.4. Average Content of Nutrients in Litter (%)

Litter type	N	P_2O_5	K_2O	CaO	Moisture content (%)
Winter wheat straw	0.50	0.20	0.90	0.30	14.3
Rye straw	0.45	0.26	1.00	0.30	14.3
Oat straw	0.65	0.35	1.60	0.40	14.0
High peat	0.80	0.10	0.07	0.22	25.0
Low peat	2.25	0.30	0.15	3.00	30.0
Tree leaves	1.10	0.25	0.30	2.00	14.0
Sawdust	0.20	0.30	0.74	1.08	25.0

Litter absorbs liquid animal excreta and the evolving ammonia nitrogen. When there is no or little litter, these substances are lost in significant amounts in barnyards and in storage. One part of straw litter may absorb two or three parts of liquid excreta, one part of low peat litter absorbs five to seven parts, and one part of high peat litter, ten to fifteen parts of liquid excreta.

Litter improves the physical, physicochemical, and biological properties of manure: it becomes less humid, less compact, and decomposes more readily in storage. Litter manure is easier to transport, handle, and apply to the soil. Litter must be used not only in barns, but also in loose yards.

The most common materials used for litter are straw and peat. These ensure top quality of manure. If straw and peat are not available, sawdust is used, but the resulting manure is of poorer quality with a low nitrogen content and a high content of slowly decomposing cellulose and lignin. This manure must be incorporated into the soil well in advance before crops are planted and, even better, after it has sufficiently decomposed during prolonged composting.

Straw to be used in litter should preferably be chopped into 10 to 15 cm lengths. Chopped straw absorbs much more urine and ammonia nitrogen, as compared to long straw, and facilitates transportation, handling, pilling, and incorporation of manure.

Peat, especially the high-moor variety, is the best material for litter. It absorbs liquid animal excreta and ammonia nitrogen of manure better than any other litter material. When used as litter in a barnyard, peat acquires much better fertilizing value, and ideal conditions are created for its decomposition after incorporation into the soil.

Used in litter should be peat with a degree of decomposition not exceeding 25 to 30 per cent and a moisture content ranging from 30 to 55 per cent. In replacement pig production, litter should preferably be made of straw or fibrous moss peat with a degree of decomposition equal to 10 to 15 per cent. A highly decomposed or more humid peat does not absorb liquid excreta as efficiently. On the other hand, dry peat has inferior wettability (and does not absorb water properly either).

Table 3.5. Daily Litter Requirements (kg) Per Animal Confined

| Animal | Cereal straw | Peat | | | Sawdust, wood shavings |
		sphagnum-cotton	sedge-hypnum	fibrous moss	
Cattle	4-6	8-11	20	7	4-6
Calves	2-3	5	10	3	2-4
Horses	3-5	5-6	8-10	4	2-4
Sheep	0.5-1	—	—	—	—
Pigs:					
farrowed sows	6-7	—	—	6-7	—
boars	2-3	—	—	2-3	2-3
feeding hogs	1-2	—	—	1-2	1.5-2
weaners	1-1.5	—	—	0.5-1	1-1.5

The optimal litter requirements depend on its quality, animal species, quantity and quality of the animal feed (Table 3.5).

A higher litter content increases the yield of manure (Table 3.6) and drastically cuts down liquid and ammonia

Table 3.6. Manure Yield and Nitrogen Loss Versus Litter Content (according to the USSR Research Institute of Fertilizers and Agronomical Soil Science)

Daily litter content per cow (kg)	Straw litter		Peat litter	
	manure accumulated over a period of 200 days (t)	nitrogen losses over 3.5 months of storage (%)	manure accumulated over a period of 200 days (t)	nitrogen losses over 3.5 months of storage (%)
2	7.2	43.9	7.7	25.2
4	8.6	31.2	9.2	13.7
6	10.2	13.3	10.4	3.4

nitrogen losses. Lower nitrogen losses are due to intensified absorption of gaseous ammonia and biological absorption of nitrogen, that is, transfer of large amounts of nitrogen into the plasma of cellulose-digesting microorganisms.

The fertilizers supplied by farms are most often in the form of manure from various animals, mixed mainly with straw litter. This manure is believed to contain an average of about 0.5% N, 0.20-0.25 P_2O_5, and 0.6% K_2O or, respectively, 5 kg N, 2-2.5 kg P_2O_5, and 6 kg K_2O per ton of manure. These figures may vary depending on animal species, feed composition and quality, type and amount of litter, manure storage conditions and time, as well as the degree of its decomposition.

Removal of Manure from Livestock Houses. Tractor-drawn push-type scrapers are often used to remove litter manure from livestock houses. To this end, manure is first shovelled from stalls into the passage, then removed by a scraper or a selfpropelled chassis with a loader.

At some farms, mechanized removal of manure of any consistency (with simultaneous loading onto vehicles or putting into storage) involves a cable or reciprocating scraper.

After manure has been removed from barnyards, it is kept in piles at the farm itself or in the field.

Changes that Occur in Litter Manure in Storage. When manure is in storage, the constituent solid excreta and litter undergo decomposition assisted by microorganisms, resulting in simpler inorganic compounds (in particular, am-

monia nitrogen forming from more complex proteinaceous substances) and secondary synthesis, for example, conversion of ammonia nitrogen into the proteins of microorganisms. Ammonia nitrogen partially converts into an amide form.

Ammonia nitrogen losses in storage are due primarily to decomposition of urine. It decomposes faster than other manure components.

Liquid animal excreta contain urea, $CO(NH_2)_2$, hippuric acid, $C_6H_5CONHCH_2COOH$, and uric acid, $C_5H_4N_4O_3$. Urea is the first to decompose when manure (and its liquid components) is in storage, followed by hippuric and then uric acid. Catalyzed by the enzyme urease released by urobacteria, urea is rapidly converted into ammonium carbonate:

$$CO(NH_2)_2 + 2H_2O = (NH_4)_2CO_3$$
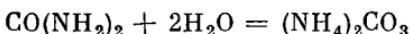
Ammonium carbonate is an unstable compound and soon decomposes into ammonia, carbon dioxide, and water:

$$(NH_4)_2CO_3 \rightarrow 2NH_3 + CO_2 + H_2O$$

Hippuric acid first decomposes into benzoic and aminoacetic acids:

$$C_6H_5CONHCH_2COOH + H_2O \rightarrow C_6H_5COOH + CH_2NH_2COOH$$

The resulting aminoacetic acid decomposes, in turn, into acetic or hydroxyacetic acid and free ammonia:

$$CH_2NH_2COOH + H_2O \rightarrow CH_2OHCOOH + NH_3$$
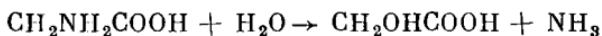
Uric acid is first converted into urea and then into ammonium acetate:

$$C_5H_4N_4O_3 + O + H_2O = C_4H_6N_4O_3 \text{ (allantoin or glyoxyl}$$
$$\text{diureide)} + CO_2$$
$$C_4H_6N_4O_3 + 2H_2O = 2CO(NH_2)_2 + HCOCOOH \text{ (glyoxylic acid)}$$
$$CO(NH_2)_2 + 2H_2O = (NH_4)_2CO_3$$
$$(NH_4)_2CO_3 = 2NH_3 + CO_2 + H_2O$$
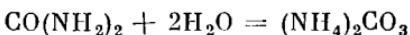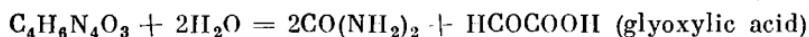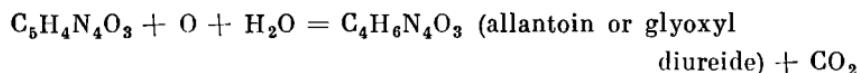
Thus, all nitrogenous compounds present in liquid animal excreta may decompose to free ammonia during storage separately or as part of manure. This is the main factor responsible for nitrogen losses in manure, especially if it is not stored properly. If peat litter is used, the forming ammo-

nia may be absorbed by peat:

(peat) $H + NH_3 \rightarrow$ (peat) NH_4 or (peat) $H + NH_4OH =$

$$= (peat)\ NH_4 + H_2O$$
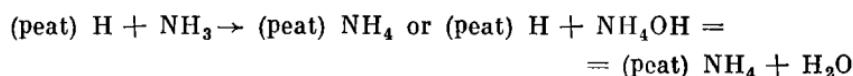
In the course of decomposition of litter manure, organic acids and humic substances characterized by high exchange capacity are formed. These substances adsorb ammonia among others, whereby it is not allowed to volatilize. When manure decomposes at a slower rate, more organic acids are accumulated in it. When its decomposition is accelerated, for example by intensive aeration, manure retains less substances capable of preventing ammonia losses.

The saturation of manure with carbon dioxide released during decomposition is also an important factor reducing liberation of ammonia. As has already been mentioned above, microorganisms partially incorporate the ammonia nitrogen present in manure into organic compounds. Therefore, by creating conditions conducive to synthetic activity of microorganisms (e.g. by adding more litter), one can further reduce nitrogen losses while manure is in storage.

Even when adequate quantities of litter are used in barnyards, it does not absorb all liquid excreta. The unabsorbed liquid should be collected in liquid-manure tanks. If the tanks are properly sealed so that the penetration of air is minimal and it is saturated with carbon dioxide and water vapour in the space confined by manure water and the lid, the possibility of ammonia losses is minimized.

According to the rate of decomposition, the organic substances in fecal matter may be divided into two groups. The first, smaller group includes compounds decomposable with relative ease, such as sugars, starch, pentosanes, pectin, and carboxylic acids. Their decomposition in the presence of oxygen is rather fast and is accompanied by a temperature rise up to 60-70 °C. The second group includes cellulose and other organic substances that decompose more slowly. The manure decomposition rate depends on the ratio between these two groups of organic compounds in it. The larger the amount of substances of the first group, the faster the decomposition. It is important that the decomposition of nitrogen-free organic components of manure should take place while it is in storage, before its incorporation into the

soil. Otherwise, there arises the danger of large quantities of nitrogen being biologically absorbed by microorganisms after manure is incorporated into the soil, with subsequent worsening of nitrogen nutrition conditions for crops.

In the presence of oxygen (under the effect of aerobic bacteria), the nitrogen-free organic substances of manure decompose into carbon dioxide and water, for example:

$$(C_6H_{10}O_5)_n + n6O_2 \rightarrow n(6CO_2 + 5H_2O)$$
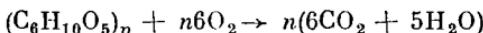
Without oxygen (under the effect of anaerobic bacteria), these substances decompose into methane and CO_2:

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow n(3CH_4 + 3CO_2)$$
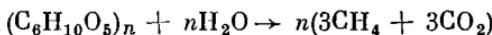
Under aerobic conditions, the organic matter of manure decomposes much faster than in the absence of oxygen.

While in storage, manure always loses weight because of liberation and volatilization of carbon dioxide, methane, and water vapour, losses of dry matter exceeding those of nitrogen. Consequently, as manure decomposes, there is an increase in the percentage content of not only phosphorus and potassium, but also of nitrogen (Table 3.7).

Table 3.7. Effect of the Degree of Manure Decomposition on Its Composition (%)

Manure components	In fresh manure	After two months of storage	After four months of storage	After 5 to 8 months of storage
Water	72.0	75.5	74.0	68.0
Organic matter	24.5	19.5	18.0	17.5
Total nitrogen	0.52	0.60	0.60	0.73
Protein nitrogen	0.33	0.45	0.54	0.68
Ammonia nitrogen	0.15	0.12	0.10	0.05
Phosphorus (P_2O_5)	0.31	0.38	0.43	0.48
Potassium (K_2O)	0.60	0.64	0.72	0.84

At early stages of decomposition, litter manure contains primarily two forms of nitrogen compounds: protein and ammonia. Subsequently, as the manure decomposition rate increases, the amount of protein nitrogen increases, while that of ammonia nitrogen decreases. In fresh and slightly decomposed manure, no nitrification takes place and no

nitrate nitrogen is formed. The absence of nitrates stems from the fact that during decomposition of manure under aerobic conditions nitrifying bacteria are killed by high temperature, whereas under anaerobic conditions they are absent altogether since they are strictly aerobic organisms. In view of the high content of cellulose in litter manure, the bacteria digesting it actively assimilate inorganic nitrogen. The absence of nitrates during storage of fresh and slightly decomposed manure means that denitrification does not occur either. Nitrate nitrogen emerges in manure in the course of its humification. Manure decomposed to a greater degree (e.g. fermented manure) contains, along with protein and ammonia nitrogens, small amounts of nitrate nitrogen (tenths of a per cent of total nitrogen).

Litter Manure of Different Degrees of Decomposition. According to the degree of decomposition, distinction is made between fresh, half-decomposed, rotted, and fermented or fine manure.

Fresh or slightly decomposed manure is that in which the litter straw still retains its typical (yellow) coloration and strength. A water extract from this manure is reddish yellow or greenish in colour.

In *half-decomposed* manure, straw loses its strength and turns dark brown. A water extract from such manure is thick and black. The weight of half-decomposed manure is 20 to 30 per cent less than that of fresh manure.

Rotted or highly decomposed manure is a black sticky mass in which individual straws (or physical components of another litter material) are not discernible. A water extract from such manure is colourless. Rotted manure weighs half as much as the initial one.

Fermented or *fine* manure is a humus-rich black homogeneous earth-like mass, which constitutes not more than 25 per cent of the initial fresh manure.

When in storage, manure does not have to undergo all these stages, unless necessary, to become fermented. This would entail huge losses of nitrogen and organic matter.

Depending on soil and climatic conditions, either rotted or half-decomposed manure is used. In south-eastern regions of the European part of the Soviet Union, susceptible to droughts and lacking irrigation, rotted manure is recommended

to be applied in spring in order to avoid further desiccation of the soil. As regards high-rainfall regions, particularly humus-poor soddy podsolic soils, half-decomposed manure is better.

If applied well in advance (e.g. during ploughing in autumn for treatment of spring crops), especially to crops with a longer vegetation period, even fresh manure is effective in these regions, while half-decomposed manure can be used in the south-east.

Litter Manure Storage Methods and Conditions. Depending on the local conditions, several methods are recommended for storing manure, each providing for different conditions of its decomposition with different losses of nitrogen and dry matter. Some of these methods are described in what follows.

Storage of Manure Under Cattle. This method is recommended for accumulating manure at farms where cattle are kept loose in runs and paddocks. Here, peat or chopped straw is spread over the loafing area in a layer 30 to 50 cm thick. Such bedding under cattle is uniformly mixed with their excreta and becomes compacted. As the tops layer becomes too damp, small portions of straw or peat are added regularly. The resulting manure is removed and used as fertilizer in summer and in autumn.

Storage of manure under cattle eliminates the need to remove it daily and to build special manure pits and install liquid-manure tanks. Cattle management becomes much cheaper, and the cost of manure goes down. If enough litter is used with timely changes, all the liquid matter remains in manure and ammonia nitrogen losses are almost nil.

The bulk of the litter manure accumulated in the stabling period must be kept in stacks.

Depending on local conditions, stacks may be compact, loose-compact, and loose.

Compact Stacking. Manure is placed in a pit or stacked in the field in layers, each layer being immediately compacted. The first layer is 5 to 6 m wide and one metre thick, its length depending on the amount of manure. Then the layer is tamped. New layers are added until the stack reaches 2.5 to 3 m in height. On top, the stack is covered by chopped straw, peat, or a layer of earth (8 to 15 cm thick).

When stacked in a compact manner, manure decomposes throughout the storage period under anaerobic conditions (except for the stack surface), and the moisture content in it remains more or less the same. In winter, the temperature inside the stack rises to not more than 20 to 25 °C, and in summer, 30 to 35 °C, which is why this type of manure storage is sometimes termed *cold*. All pores of compactly stacked manure are saturated with carbon dioxide and water vapour, which prevents decomposition of ammonium carbonate into free ammonia, carbon dioxide, and water. Organic matter and nitrogen losses in compact stacking are much lower as compared to other stacking techniques.

Compact stacking is intended to produce half-decomposed manure, which will take three to four winter months after manure has been stacked. Manure stacked in this way becomes rotted after seven to eight months.

Loose-Compact Stacking. Fresh manure is first placed loosely, without compaction, in metre-thick layers, then, when the temperature in a layer reaches 60 to 70 °C (on the third to fifth day), it is compacted as much as possible. Thus, one layer is placed on another to the full height of the stack, each layer being compacted only after its temperature has gone high up.

At the first stage of manure storage (before compaction), intensive aerobic decomposition takes place in the stack, involving thermophilic bacteria, with heavy losses of nitrogen and organic matter. In order to minimize nitrogen losses, more litter is added. The high temperature inherent in loose storage enables manure to be rid of pathogens causing gastrointestinal disorders.

At the second stage (after compaction), the manure temperature goes down to 30-35 °C, and its decomposition continues under anaerobic conditions.

When stored loosely with subsequent compaction, manure decomposes much faster than in the case of compact stacking. Half-decomposed manure forms after one and a half to two months, while it takes four to five months after stacking for manure to rot completely.

Loose-compact stacking is recommended when manure has to decompose as fully as possible within a relatively short period of time or when it is found to contain organisms

causing gastrointestinal diseases and has to be biothermally
decontaminated.

It is also used to speed up the decomposition of manure
containing much straw litter.

Loose stacking or piling. Manure is piled and kept without
compaction. In this case, manure decomposes under aerobic
conditions at high temperature (hot manure) with inevitably
high nitrogen and organic matter losses as well as segrega-
tion of manure water. This type of storage is permissible only
for peat manure.

The losses of nitrogen, organic matter, and liquid are
maximum when manure is stored loosely, in piles, the losses
being minimum in compact stacking, while loose-compact
stacking falls between the two (Table 3.8).

Table 3.8. Losses of Nitrogen, Liquid, and Organic Matter of Manure
Over a Period of 4 Months ($\%$), Depending on the Manner in Which
It is Stored and Litter Type

Storage	Losses from straw manure of			Losses from peat manure of		
	organic matter	nitro-gen	liquid	organic matter	nitro-gen	liquid
Loose	32.6	31.4	10.5	40.0	25.3	4.3
Loose-compact	24.6	21.6	5.4	32.9	17.0	3.4
Compact	12.2	10.7	1.9	7.0	1.0	0.6

Compact stacking and use of peat litter minimize losses
of nitrogen, organic matter, and liquid.

Storage of Litter Manure in Manure Yards. Depending on
local conditions, manure may be accumulated and stored
both in special manure yards near livestock houses and in
stacks or piles in the field to be manured.

There are two main types of storage facilities in manure
yards: pits and barns. When the groundwater table is high,
manure should preferably be stored in barns. In arid re-
gions, where manure dries up quickly, pits are preferable.
Storage in manure pits makes it easier to create anaerobic

conditions for decomposition of manure with insignificant losses of nitrogen and organic matter.

Any type of manure storage facility must meet the following requirements:

to avoid losses of manure water, the storage facility must have an impermeable bottom, the best being that made of concrete; such a bottom must bear the load of the vehicles and other machines used to handle manure;

troughs must be provided along the longitudinal sides of the manure pit or barn to collect manure water;

the pit or barn bottom must be inclined towards the manure water tank;

ditches must be dug along the manure pit or barn (outside) to collect rain and melt water;

to facilitate haulage of manure, approach ramps must be provided at the entry and exit of the barn or pit, across its narrow sides;

a barn or pit must be built on elevated ground that cannot be inundated, at an appropriate distance (at least 200 m) from the nearest habitation.

Storage facilities for manure must not be built on marshy or inundated ground as well as near rivers, lakes, ponds, and wells. The site for a manure pit or barn is usually selected together with a veterinarian.

The size of a manure pit or barn depends on the amount of manure to be accumulated over the stabling period. The approximate floor space area (in m^2) per animal to store manure over a period of two and a half to three months at a manure stack height of 1.5 m is as follows:

cattle	2.0-2.5
working horses	1.40-1.75
calves and foals	1.00-1.25
pigs	0.40-0.50
sheep	0.20-0.30

In the course of decomposition with losses of organic matter, manure gives up its liquid (manure water) which must be collected in manure water tanks located below the pit or barn bottom, along its longitudinal sides. The capacity of such a tank must be 1.3 m^3 per 100 tons of manure, which corresponds to a volume of at least three to four cubic metres.

The collected manure water can be used directly as fertilizer, in composting, or to wet manure in the pit or barn as it gradually dries up.

In stacking, one must make sure that manure of different degrees of decomposition does not get mixed, being stored in separate parts of the pit or barn. Manure is placed in stacks 2 to 3 m wide across the pit or barn, beginning from one of its ends, each layer being compacted and the stack being brought to its final height (2.5-2 m). After the first stack has been completed, the newly delivered manure is placed in a second, third, and subsequent stacks till the pit or barn is filled completely. Stacks must be arranged close to one another. If this order is maintained, one end of the pit or barn will contain manure decomposed to a greater degree (in the first stacks), while at the opposite end manure will be less decomposed. This permits taking manure of the desired quality.

When manure becomes overheated, it must be immediately quenched with manure water and compacted.

Storage of Manure in Field Stacks. In view of the fact that vehicles are hard to get in spring and in summer because that is when they are used to the full, it is advisable to haul manure to the field in winter. This may include manure already seasoned in the manure yard or fresh manure straight from barnyards.

When hauled in winter, manure is stacked on high ground that will not be inundated in spring. The stacking area is cleaned of snow, then covered with a peat or chopped straw layer 20 to 25 cm thick. Manure is placed in rather big stacks and compacted to prevent freezing and nitrogen losses. Stacks may be three, four, and more metres wide and two to two and a half metres high.

Stacks are so arranged in the field as to minimize idle runs of manure spreaders.

Stacking should best be done in rows (Fig. 3.2). The spacing between rows equals the working width of the spreader, which is given by the formula:

$$S_1 = \frac{10\,000 \cdot L}{RW}$$

where S_1 is the row spacing (in m), L is the load-carrying capacity of the manure spreader (in t), R is the manure rate

(in t/ha), W is the spreading width (in m), and 10 000 is the area of a hectare (in m²).

At the same time, the spacing between stacks in a row must be determined, which is a function of stack weight, load-carrying capacity of the manure spreader, and spreading width:

$$S_2 = \frac{M \cdot W}{L}$$

where S_2 is the stack spacing in a row (in m), M is the stack weight (in t), W is the spreading width (in m), and L is the load-carrying capacity of the manure spreader (in t).
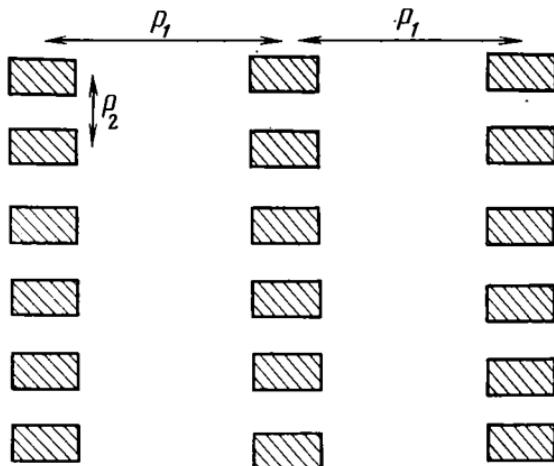

Fig. 3.2. Arrangement of manure stacks in the field

To avoid freezing, each stack must be completed in winter within one or two days, after which the stack is covered with a peat or chopped straw layer 15 to 25 cm thick.

Fresh or half-decomposed manure should not be stored in fields in small piles or heaps because it will freeze in winter or dry up in spring and in summer. As a result, the manure quality is drastically impaired. Moreover, spots occupied by small stacks, to say nothing of even smaller piles, delay field cultivation in spring because the soil beneath thaws later.

Ways to Minimize Losses in Litter Manure Storage.
When manure is accumulated and stored in a wrong way, it
loses large amounts of nutrients, whereby its fertilizing
value is reduced. In the course of its decomposition, manure
loses most of its nitrogen in the form of ammonia. If liquid
animal excreta and liquid manure are drained aside or
seep into the ground under the stack, not only nitrogen but
also sizable amounts of potassium are lost.

Among the usual procedures that not only substantially
increase the yield of manure and minimize nutrient losses,
but also considerably improve its quality are addition of
more litter, making litter from peat and chopped straw,
compact stacking of manure, and installation of liquid-
manure tanks near barn and manure yards. Other important
means for enhancing the fertilizing value of manure include
addition of ground phosphate rock to it and composting of
manure with peat and other materials.

Addition of Ground Phosphate Rock. When ground phos
phate rock is added to manure, its phosphorus content in-
creases, the microbiological processes are activated, humifica-
tion of manure is accelerated, and appropriate conditions are
created for intensive absorption of nitrogen by microorgan-
isms during storage. All this cuts down ammonia nitrogen
losses in storage (Table 3.9).

Table 3.9. Reduction of Organic Matter and Nitrogen Losses from
Manure Due to Its Being Composted with Phosphorus Fertilizers (ac-
cording to Mamchenkov)

Experimental conditions	Losses (% of the initial content) over 4 months of storage	
	organic matter	nitrogen
Without composting	58.1	19.6
Composting with 3% ground phosphate rock	42.6	5.4
Composting with 2% superphosphate	41.4	3.3

Composting of manure with ground phosphate rock not
only improves the manure quality, but also enhances the
effectiveness of ground phosphate rock, which is the cheapest

but poorly soluble phosphorus fertilizer. The carbonic acid and carboxylic acids evolving on decomposition of manure render the phosphorus of ground phosphate rock more readily available to plants:

$$Ca_3(PO_4)_2 + 2H_2CO_3 \rightarrow 2CaHPO_4 + Ca(HCO_3)_2$$
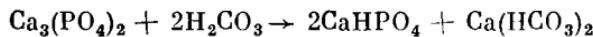
When composted with manure, the phosphorus of ground phosphate rock is partially digested by microorganisms and temporarily passes into an organic form (into microbial plasma). This phosphorus becomes available after the subsequent mineralization of microorganisms.

In composts, ground phosphate rock must constitute one to four per cent of the manure weight (i.e. 10-40 or, more typically, 20-30 kg of ground phosphate rock per ton of manure). This ratio can be optimized with due account for the planned compost rate so that each hectare of arable land receives with it the necessary amount of phosphorus fertilizer.

Ground phosphate rock may be added to manure at any time while it is kept in barnyards prior to being incorporated. The longer the interaction between the two types of fertilizer and the more intimately they are mixed, the greater the effectiveness of the compost. Therefore, it is best to add ground phosphate rock to manure in barnyards directly in stalls before the latter are cleaned. In such cases, the subsequent handling and storage of manure involve better mixing of ground phosphate rock with manure, and the interaction between them is more complete. Top quality compost can be obtained if ground phosphate rock is added to manure in stalls or loafing yards.

Ground phosphate rock may also be added to manure while it is being stacked. The calculated amount of ground phosphate rock is added layerwise by evenly spreading it over manure after placing each layer 10 to 20 cm thick.

Manure-phosphorite composts in stacks mature (half-decomposed manure) for two to three months in summer and three to four months in winter.

The results of field experiments at the Central Experimental Station of the USSR Research Institute of Fertilizers and Agronomical Soil Science, conducted on soddy podsolic loam, indicate that incorporation of manure-phosphorite

compost into the soil increases crop yields to a greater extent
as compared to the total increase due to separate application
of manure and ground phosphate rock to different fields.
The effect of these fertilizers on the first crop (potatoes
and winter rye), when applied simultaneously without hav-
ing been composted, was weaker than that produced by the
compost. However, the aftereffect on the yield of the second
crop (spring wheat and perennial grasses) was almost the
same (Table 3.10).

Table 3.10. Effect and Aftereffect of Manure-Phosphorite Compost
and a Mixture of Manure and Ground Phosphate Rock on the Yield
of Rotating Crops

Crop	Yield (cent/ha)				
	without fertilizer	after manure (20 t/ha)	after ground phosphate rock (3 cent/ha)	after manure and ground phosphate rock	
				compost	field mixture
Potato	234.0	307.0	272.0	354.0	314.0
Spring wheat (aftereffect)	12.1	14.7	13.2	16.7	16.5
Winter rye	10.4	17.8	10.9	21.3	19.8
Perennial grass hay (aftereffect)	9.1	32.4	14.8	48.3	45.0

Manure-phosphorite composts should preferably be applied
during ploughing at a rate of 20 t/ha. The basal fertilizer
can be applied at higher rates to vegetables, ensilage crops,
potatoes, and root crops. The effectiveness of such composts
can be enhanced considerably if they are applied together
with nitrogen fertilizers.

Calculation of Litter Manure Requirements. To plan appli-
cation of fertilizers one must have at least an approximate
idea of how much manure has been accumulated at the
farm (Table 3.11).

The quantity of litter manure accumulated at the farm
can be determined through direct measurement of the stack
volume multiplied by the weight of each cubic metre of the
fertilizer. The stack volume is found by multiplying its
length by its width and height. A cubic metre of loose fresh

Table 3.11. Approximate Quantity of Fresh Manure Accumulated Daily Per Animal at Different Straw Litter Contents

Daily litter content (kg)	Daily manure yield (kg) per animal			
	cattle	horses	pigs	sheep and goats
0 (without litter)*	25	17	1.7	2
1	28	21	4.7	4
2	32	24	8.0	5
3	37	25	9.0	—
4	39	26	—	—
5	42	27	—	—
6	44	28	—	—

* Manure without litter retains only solid excreta, while the liquid ones are lost.

manure weighs 0.3 to 0.4 t, that of compacted manure 0.7 t, that of half-decomposed manure about 0.8 t, and that of rotted manure 0.9 t.

Apart from determining the actual quantity of accumulated manure, it is also important to estimate its planned yield. In such calculations, the yield of fresh manure is determined first, then an appropriate correction is introduced for the desired degree of its decomposition.

Calculation of the fresh manure yield is based on the fact that almost half of the dry matter in the feed digested by an animal $\frac{F}{2}$ and all of the dry litter (L) pass into manure. Since fresh manure contains only 25 per cent of dry matter (and 75% water), the quantity of manure will be four times the total weight of litter and undigested part of the feed. Hence, the manure yield (M) is calculated using the formula:

$$M = \left(\frac{F}{2} + L\right) \times 4$$

According to Table 3.11, the total yield of fresh manure from the entire stock over the stabling period (Y_s) can be

calculated from the formula:

$$Y_s = \frac{Y_d D_s C_1}{1000}$$

where Y_d is the daily yield of fresh manure (in kg according to Table 3.11), D_s is the duration of the stabling period (in days), C_1 is the cattle stock (in livestock capita), and 1000 is the kilogram-to-ton conversion factor.

After the estimated fresh manure yield has been found, the correction for the degree of decomposition is introduced and the amount of decomposed manure is established. For example, the weight of half-decomposed manure is determined by multiplying the found weight of fresh manure by a factor of 0.7 or 0.8 (the weight of half-decomposed manure constitutes 70 to 80 per cent of the initial manure weight). To determine the weight of half-decomposed manure a factor of 0.5 is used and, for rotted manure, the factor is 0.25.

In calculating manure accumulation at a farm, a head of cattle is equated (in terms of manure yield per cow) with one and a half horses, two heifers, three to five calves, four to five adult pigs, and ten sheep.

Litter Manure as a Source of Nutrients for Plants. Manure is a complete organic fertilizer containing all the nutrients required by plants. After incorporation into the soil, it is mineralized by microorganisms. According to the results of perennial experiments carried out on soddy podsolic soils at the Pryanishnikov Agrochemical Experimental Station in Dolgoprudny, of the total amount of organic matter in the incorporated manure, an average of 72 per cent is mineralized with 28 per cent passing into soil humus. The mineralization rate depends on manure quality, soil properties, water and air regimes in the soil, its reaction, and other factors. Most of the carbon present in the organic substances of manure is oxidized to carbon dioxide during decomposition in the soil, the amount of the carbon dioxide formed in the latter being inversely proportional to the degree of manure decomposition before incorporation.

The availability of manure nitrogen and ash elements to plants depends on the composition of manure, the degree of its decomposition prior to incorporation, and the rate

of its mineralization once in the soil. The most abundant of the three basic nutrients in manure is potassium present in it in the most mobile form. Characteristically, potassium in manure takes a chlorine-free form, which makes it by far more superior over the potassium in chlorine-containing inorganic fertilizers, especially with respect to such chlorine-sensitive crops as tobacco, potatoes, berries, and citruses. Potassium of both manure and inorganic fertilizers is taken up by the first crop at about the same rate (60-70 % of the incorporated amount).

Manure phosphorus is present primarily in solid excreta and litter. Its content in liquid excreta is extremely low. While the organic matter undergoes mineralization, phosphorus is separated in the form of orthophosphates of different degrees of solubility. By virtue of the protective effect of the organic matter, these phosphates are fixed in the soil to a much lesser extent, as compared to the phosphorus of inorganic fertilizers incorporated in their pure form. Therefore, manure phosphorus is more readily available to plants within the first year after manuring, than the phosphorus of inorganic fertilizers, and constitutes 35 and more per cent of the total phosphorus in manure (versus 15-20% in inorganic fertilizers). The organic (humic) substances of manure enhance the availability of not only manure phosphorus, but also that of the soil and the phosphorus fertilizers applied at the same time.

Nitrogen can be found in all manure components. Yet only the nitrogen of liquid excreta can be taken up directly by plants. The nitrogenous substances of fecal matter and litter (just as their phosphorus compounds) become available only after mineralization. The end product of decomposition of the nitrogenous substances of manure in the soil is ammonia nitrogen, which is directly taken up by plants and microorganisms or nitrified. Denitrification is also possible in an alkaline medium at a high moisture content in the soil, oxygen deficiency, and a high cellulose content in the incorporated manure. Part of the fertilizer nitrogen passes into the soil humus under the action of microorganisms. Thus, manure, especially if slightly decomposed, serves as a source of nitrogen not only to the first crop under treatment, but also to the subsequent ones. Within the first year

after manuring, plants take up mostly ammonia nitrogen from manure. As a result of mineralization of the organic matter of manure, it satisfies better, within the first year, the nitrogen requirements of crops with a relatively long vegetation period (late varieties of cabbage or potatoes, root crops, maize, winter cereals, etc.). The longer the vegetation period of crops, the higher the factor of utilization of nitrogen and other manure nutrients by them.

The uptake of manure nitrogen by the first crop under treatment depends largely on the ammonia nitrogen left in manure after its storage.

In the case of peat litter and compact stacking of manure, it retains a lot more ammonia nitrogen, and the rate of manure nitrogen uptake by the first crop under treatment is higher.

The factor of utilization of litter manure nitrogen by the first crop under treatment varies depending on manure origin. It is the highest in the case of sheep manure (about 30% of the total nitrogen content), slightly lower for horse (about 20%) and cow (about 18%) manure, and the lowest for pig manure (about 10%).

This factor is also strongly dependent on the degree of manure decomposition. For example, in an experiment conducted at the USSR Research Institute of Fertilizers and Agronomical Soil Science, the first crop under treatment took up 7.8 per cent of total nitrogen from slightly decomposed manure, 23.4 per cent from half-decomposed manure, 17.5 per cent from rotted manure, and 4.8 per cent from fermented manure. Hence, it is in half-decomposed manure that nitrogen is most readily available to crops. Next in this respect comes rotted manure and last, fermented manure.

A major portion of the nitrogen from incorporated half-decomposed manure, mineralized in the course of its further decomposition in the soil, is absorbed by microorganisms. If such manure is incorporated shortly before the crop to be treated is sown, the crop will suffer from nitrogen deficiency early in the vegetation period. But when half-decomposed manure is incorporated well in advance, for example during autumn ploughing to treat spring crops, its nitrogen and other nutrients are more readily available.

It is believed that the first crop takes up an average of

20 to 25 per cent of manure nitrogen, which is much lower than the inorganic fertilizer nitrogen uptake rate (60-70%).

Thus, manure phosphorus is taken up by the first crop under treatment more intensively than superphosphate phosphorus, while manure nitrogen is taken up less intensively than that of nitrogen fertilizers. The rate of manure potassium uptake approaches that of potassium uptake from inorganic fertilizers. Therefore, when manure is applied directly to various farm crops (especially row ones), it is often necessary to supplement it with nitrogen fertilizers in the first place.

Owing to the high content of potassium in manure and its high mobility, the potassium requirements of the first crop to be treated by usual manure rates can be met without addition of potassium fertilizers.

For example, if it is assumed that a ton of manure contains an average of 5 kg N, 2.5 kg P_2O_5, and 6 kg K_2O, manuring at a normal rate (30 t/ha) will bring about 150 kg N, 75 kg P_2O_5, and 180 kg K_2O into the soil. Of this amount of manure-derived nutrients, the first crop may take up (at average utilization factors of 20-25% N, 30% P_2O_5, and 60% K_2O from manure within the first year) about 30 to 40 kg N, 22.5 kg P_2O_5, and 100 kg K_2O. Comparison of these nutrient quantities with yield removal of nitrogen, phosphorus, and potassium (see Table 2.6, Vol. 1) clearly indicates that manure must be supplemented first of all with nitrogen fertilizers (particularly in the case of humus-poor soils), then phosphorus and, last, potassium fertilizers to ensure the necessary basic nutrient ratio.

When taken into account is not only the direct effect of manure on the first crop under treatment, but also its long-term aftereffect, it turns out that its phosphorus and potassium are more readily taken up by crops than the same nutrients from equivalent amounts of inorganic fertilizers. At the same time, manure nitrogen is taken up in smaller amounts, as compared to that of inorganic fertilizers. Accordingly, as indicated by experimental results, the overall effect of manure, including its aftereffect, on crop yields is somewhat less pronounced than that of equivalent rates of inorganic fertilizers. The lower rate of manure nitrogen uptake by crops is due, apart from the effect of possible losses before

incorporation of manure, to the fact that the soil is en-
riched with humus to a greater extent (i.e. nitrogen from ma-
nure partially passes into the soil humus) than in the case
of inorganic fertilizers. Therefore, when applied to adequate-
ly cultivated soils, manure has no advantages over an equiv-
alent amount of inorganic fertilizers. On the contrary, in
the case of humus-poor and inadequately cultivated soils,
application of manure and other organic fertilizers is a pre-
requisite for improving the soil properties and enhancing
the effectiveness of inorganic fertilizers.

Application of Litter Manure. The most effective way to
apply litter manure is ploughing it down into a moist soil
layer.

The rate of manure to be ploughed under varies from 15
to 50 and more tons per hectare depending on the degree of
its decomposition, crops to be treated, soil and climatic con-
ditions. Grain crops (particularly winter ones) growing in
various zones are to be manured at rates ranging from 15
to 25 t/ha (18-20 t/ha on the average). Higher rates of less
decomposed manure are commonly used in northern re-
gions of the country. In arid regions without irrigation, where
fully decomposed manure is recommended, its rates to be ap-
plied to cereals are reduced to 12-15 t/ha.

Ensilage crops, vegetables, potatoes, and root crops are
manured at higher rates than cereals. For example, potatoes
grown on soddy podsolic loam may receive 25 to 30 t/ha
and, if grown on light sandy and sandy-loam soils, even as
much as 30 to 40 tons of manure per hectare. About the same
rates are considered to be optimal for sugar beet. Maize,
hemp, and cucumbers grown in the Non-Black Earth zone
are often recommended to be treated with 40 to 50 tons of
manure per hectare, while those cultivated in the chernozem
belt are to be treated with 25 to 35 t/ha. When these crops
are sown again on the same fields, the manure rates are re-
duced. Combination of manure with inorganic fertilizers per-
mits the above rates to be cut down significantly.

Row crops are more sensitive to increased manure rates
than cereals (Table 3.12).

The poorer a soil is in humus and mobile nutrients, the
more manure must be incorporated, all other things being
equal.

To rapidly increase the fertility of undercultivated soils
and to maximize crop yields, it is expedient to apply at
once higher manure rates to the rotating crops most sensi-

Table 3.12. Winter Rye and Potato Yield Increases Due to Manure
Applied at Different Rates to Soddy Podsolic Soils at the Polesye
and Zhitomir Experimental Stations (according to Vyshinsky, 1959)

Crop and product	Yield increase (cent/ha) due to manure (t/ha)			Crop return (kg) per ton of manure		
	18-30	35-40	54	first 18 t	second 18 t	third 18 t
Winter rye (grain)	2.7	5.7	7.6	15	16	11
Potato (tubers)	37.2	79.9	129.5	207	237	276

tive to it (maize, cucumbers, potatoes, beets, winter crops,
etc.), while other crops should preferably be treated with
inorganic fertilizers. To ensure an adequate humus balance
in crop rotations with one or two courses of perennial grasses
requires an average of 8 to 10 t/ha of manure to be ap-
plied annually to loamy soils and 15 to 20 t/ha to light soils.

In deciding where and how to apply manure and other
organic fertilizers in crop rotation, one must take into con-
sideration the biological characteristics and commercial val-
ue of each crop. In field crop rotation, manure should
preferably be applied to winter or row crows or, if the farm
has adequate supplies of manure, to both. For treating
winter crops to be grown on cropped fallow, manure should
best be applied to the fallow crop.

Organic fertilizers are especially valuable when applied
to crops sensitive to a high concentration of salts in the
soil solution and characterized by a long vegetation period,
as well as to crops responsive to carbon dioxide nutrition.
For instance, in vegetable rotation, manure should first of
all be applied (in combination with a small amount of inor-
ganic fertilizers) to cucumbers, which are eagerly responsive
to organic fertilizers and more sensitive to the soil solution
concentration. Unlike cucumbers, cabbage and beets re-
sponding positively to manuring are more tolerant to a high

salt concentration; hence, in order to ensure high yields of
these crops, increased rates of inorganic fertilizers can be
used in combination with aftereffect of manure. Applica-
tion of fresh or half-decomposed manure to carrots and par-
sley causes bifurcation of the root, which reduces the com-
mercial value of these crops. Such crops must be sown two
to three years after incorporation of organic fertilizers or
immediately after incorporation of fermented manure to-
gether with inorganic fertilizers.

Because of its uneven distribution in the soil, fresh manure
leads to irregular density of flax plants and impairs their
quality. Therefore, in flax rotations, such manure should
rather be applied to the precursors, while flax itself should
be treated with inorganic fertilizers.

The requirements to the degree of manure decomposition
depend on certain conditions. In arid regions of the country,
preference is given to rotted manure, in the Non-Black Earth
zone, half-decomposed manure is preferred, and even fresh
manure can be used there during autumn ploughing. The
selection of manure according to the degree of its decomposi-
tion is governed by the type of crop to be treated with it.
For example, crops with a shorter vegetation period (early
varieties of cabbage and potatoes, onions, etc.) develop
better when treated with more decomposed manure, whereas
crops harvested late (late varieties of cabbage and potatoes,
beets, beans, etc.) and winter cereals grow well when treat-
ed with less decomposed manure, provided it has been in-
corporated in advance.

The vegetables responding well to fresh manure include
cucumbers, while fermented and rotted manure are preferred
by onions and carrots.

The effectiveness of manure depends not only on how it is
stored and accumulated, but also on how carefully and
evenly it is spread over the field and how soon it is incorpo-
rated into the soil after being spread.

To transfer manure (and other organic fertilizers) from
stacks to any type of vehicle, loaders are used. The degree
of decomposition of manure varies depending on the part
of stack from which it is taken. In order to avoid uneven (in
terms of quality) distribution of manure over the field, it is
picked by the loader vertically from a small area but over

the entire height of the stack, rather than horizontally from
the stack surface.

Once spread, fresh or half-decomposed manure must im-
mediately be incorporated into the soil. The effectiveness
of manure left unincorporated for 24 hours drops sharply,
while manure spread but not incorporated loses all of its am-
monia nitrogen within the first few days.

The depth to which manure is ploughed under ranges from
15 to 30 cm depending on local conditions. More specifically,
it depends on the degree of manure decomposition in the soil
and the rate of uptake of its nutrients by the first crop to
be treated. A shallow depth of incorporation into a moist
soil promotes the decomposition of manure. Deep incorpora-
tion, especially into a waterlogged soil, renders its decompo-
sition difficult because of insufficient aeration. If a soil con-
tains little moisture (in arid regions), shallow incorpora-
tion creates conditions unfavourable for manure decompo-
sition and is conducive to further desiccation of the soil.

The heavy soils of northern parts of the Non-Black Earth
zone require more shallow incorporation, while for light
soils manure must be incorporated deeper. In arid regions or
in the case of dry soils, manure must be placed deeper than
for adequately moistened soils in high-rainfall areas. The
depth of manure incorporation also depends on the crop to
be treated and on the penetration of its roots into the soil.

Manure is characterized by a marked direct action and a
long aftereffect, especially when applied at high rates. As
a rule, yield increases due to aftereffect of manure over sev-
eral years are much higher than those due to its direct action.
If the sum of yield increments due to manure is taken
equal to 100 per cent, those due to its aftereffect account for
60 to 80 per cent and those due to its direct action account
for 20 to 40 per cent. The direct action of manure is most
pronounced in the north of the Non-Black Earth zone. This
is so because soils in this region contain little humus and
nutrients, abound in mobile aluminium, and exhibit high
acidity. As one goes south and east, manure gradually be-
comes less effective.

The duration of the residual effect of manure in different
parts of the country varies according to local soil and climat-
ic conditions. In the north (e.g. in the Arkhangelsk Region),

especially on light soils, the aftereffect persists for no more
than two or three years, which means that manuring should
be done more often. Southwards, the length of the manure
aftereffect increases and reaches a maximum in the cherno-
zem belt (5, 7, and more years). Farther south, the duration
of both direct and residual effects of manure is shortened.
The length of its aftereffect is also dependent on soil texture.
For instance, in the case of the clayey and loamy soils of
the Non-Black Earth zone, optimal manure rates produce
an appreciable effect on yields, sometimes throughout the
entire cycle of 7- to 8-course crop rotation. Because manure
decomposes more quickly in sandy soils, its aftereffect on
them is shorter in duration—two to three years.

In the numerous experiments carried out in different parts
of the USSR, each ton of manure increased the grain yield
up to one centner in an 8- to 10-course rotation cycle. How-
ever, the effectiveness of manure largely depends on the soil

Table 3.13. Direct and Residual Effects of Manure on Crop Yields
(increase in grain yield, cent/ha)

Zone	Effect on the first (winter) crop	Aftereffect		After three years
		1st year	2nd year	
Non-Black Earth	6.5	3.4	2.5	12.4
Black-Earth (chernozem)	4.5	4.0	3.2	11.7
South-Eastern	2.2	3.5	2.0	7.7

and climatic conditions as well as on the crop rotation pat-
tern. It is more effective in row and fruit crop rotations in
areas with soddy podsolic soils. Already within the first
three years after manuring at usual rates (15-20 t/ha), addi-
tional 7 to 12 centners of grain per hectare can be harvested
(Table 3.13).

3.2 Manure Without Litter

The manure without litter, accumulated at large animal farms, is essentially a mixture of solid and liquid animal excreta diluted with water to some or other extent. Where the amount of this water is determined by the conditions prevailing at a particular farm (losses from automatic drinking bowls, water used for rinsing udders or feeders, etc.), the water content of such manure does not exceed 90 to 91 per cent. Such manure is called semiliquid (Table 3.14).

Table 3.14. Approximate Composition of Semiliquid Manure

Animals	Percentage content of							
	water	dry matter	total nitrogen	ammo-nia nitrogen	P_2O_5	K_2O	CaO	MgO
Cattle	88.5	11.5	0.40	0.25	0.20	0.45	0.15	0.1
Pigs	89.5	10.5	0.50	0.35	0.25	0.24	0.21	0.1

Further dilution of manure with water is most undesirable for its sharply increases its volume, hence transportation cost. The quantity of water is especially high when manure is hosed down. Increasing the water content in manure to 95 per cent doubles its volume, while at 98 per cent the volume is increased five-fold, as compared to the initial volume of excreta. Manure without litter containing more than 92 per cent water is called liquid manure. 50 to 70 per cent of the nitrogen contained in manure without litter is in ammonia form, and 30 to 50 per cent, in organic form. At the same time, the ammonia form accounts for an average of 20 per cent of total nitrogen in such manure. Thus, the nitrogen of manure without litter is more readily available to the first crop under treatment. The phosphorus of liquid manure is also more readily available to the first crop than that of litter manure. All of potassium in manure without litter is in a dissolved state (in the liquid phase), and crops can easily take it up. Therefore, the effect of liquid and semiliquid manure on the yield of the first crop under treatment is more pronounced, as compared to litter manure, while its after-effect is somewhat weaker.

In some instances, manure without litter is segregated into solid and liquid fractions, each being used separately as fertilizer. Here, 20 to 25 per cent of all nutrients are in the solid fraction, while 75 to 80 per cent are in the liquid one. When manure is heavily diluted with water, the total amount of the nutrients passing into the liquid fraction reaches 95 per cent.

The solid fraction of liquid manure contains almost the same quantity of nitrogen and phosphorus as litter manure. As far as the content of other nutrients is concerned, the solid fraction is also much richer than the liquid fraction or even liquid manure not segregated into fractions (Table 3.15).

Table 3.15. Content of Dry Matter, Nitrogen, Phosphorus, and Potassium in Liquid Pig Manure and Its Fractions (according to Ilchenko, 1977)

Liquid manure and fractions	Percentage content of				
	dry matter	total nitrogen	ammonia nitrogen	P_2O_5	K_2O
Unsegregated liquid manure	2-4.4	0.15-0.18	0.07-0.11	0.03-0.05	0.10-0.15
Liquid fraction	0.4-0.5	0.05-0.06	0.04-0.05	0.014-0.019	0.03-0.04
Solid fraction	21.6-24.2	0.25-0.50	0.02-0.15	0.12-0.25	0.07-0.23

Removal of Manure Without Litter from Livestock Houses. A gravity flow system is advisable to use for removal of liquid and semiliquid manure from livestock houses whereby manure is transferred hydraulically on a liquid "cushion" (Fig. 3.3). When liquid manure is removed by gravity flow, the fecal matter of animals finds its way through slatted floors into manure channels inclined at 0.5 to 1°. The liquid and solid excreta flow by gravity into a manure receiver that can hold a weekly yield of manure. From the receivers, manure is pumped through a pipe into a manure tank or special cisterns on wheels.

For the gravity flow system to operate normally, no litter is used under animals. It is also important to prevent leftovers of animal feed from getting into the manure channel. The latter has several stationary steps forming a cascade (the first being 10-12 m long and the others, 15 to

20 m). Each subsequent step must be 10 to 15 cm below the preceding one. The manure channel at the end of each step must be provided with exhaust ventilation so that gases from beneath the slatted floor do not escape into the barn.

The entire system, from the manure channels to the tank, must be reliably waterproofed with a material resistant to
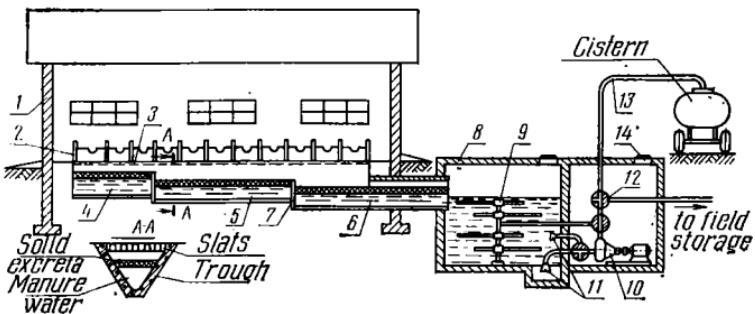

Fig. 3.3. Manure removal by the cascade method
1—cowhouse, 2—stalls, 3—slats, 4—1st stage channel, 5—2nd stage channel, 6—3d stage channel, 7—channel step, 8—manure tank, 9—reactive by hydraulic agitation, 10—manure pump, 11—inlet pipe, 12—cock, 13—loader, 14—manhole.

the corrosive action of solutions and gases, in order to prevent seepage of liquid manure into the ground and pollution of surface and subterranean waters.

Liquid manure is checked in the receiver for infection with dangerous animal disease pathogens. There should be at least two receivers where manure would be allowed to stay for seven to eight days so that, while one receiver is being filled, manure is tested in the other. If manure is not infected, it is pumped into the tank. Otherwise, manure is disinfected under the supervision of a veterinary inspector, and a decision must be taken whether it can be used as fertilizer.

Storage of Manure Without Litter. For this manure to be kept as long as two to six months (depending on local conditions), storage facilities are built at the farm or in the field. The former are completely enclosed and have a capacity to hold 25 to 40 per cent of the manure yield, while the latter are essentially open pits capable of holding 60 to 75 per cent of the manure yield. The pits are located in the centre of the fields to be fertilized. If possible, both types of storage fa-

cilities should be connected via pipes to the manure removal (disposal) system. If not, manure is carried to the field pits in cisterns.

If pipelines are available, the entire stock of manure can be kept at the farm. The farm storage facilities should be linked by pipes with the field stations for loading manure-spreading cisterns.

While in storage, manure without litter soon becomes stratified into three layers with a dense floating layer on top, the sediment at the bottom, and clarified liquid in between. To ensure homogeneity of manure, each storage facility must have an agitator. Manure must be periodically agitated in storage lest a hard crust forms on its surface. While manure is being handled, that is, loaded into spreading cisterns or pumped through pipelines, it must be agitated several times a day.

It is important for normal operation of pumps, pipelines, spreading cisterns, and sprinklers that the foreign matter in manure (straw, hay, etc.) should be shredded by means of special devices. Such shredding is required both before manure is put into storage and prior to its being discharged.

The sections of manure enclosures must be provided with covered manholes through which manure is mixed and discharged into vehicles. The roads approaching the storage facilities must have a hard pavement. Gutters must be dug around the storage facilities.

Manure barns must be ventilated to avoid accumulation of large amounts of methane, hydrogen sulphide, ammonia, and other gases in them. Striking a match in such a barn may trigger an explosion, and inspection of pits without a gas mask may cause serious poisoning.

Decomposition of Manure Without Litter. As long as manure without litter is kept in receivers or in the tank (under anaerobic conditions), all decomposition processes are much slower than in the case of litter manure. Therefore, the losses of nitrogen in the form of ammonia and those of organic matter from stored manure without litter are much lower, as compared to stacked ordinary manure.

Since manure without litter retains large amounts of available ammonia nitrogen, it contains more nitrogen (up to 40%) within the first year after application than litter ma-

nure (about 20%). 40 to 50 per cent of phosphorus (versus 30-40% from litter manure) and 70 to 90 per cent of potassium (versus 60-70% from litter manure) are taken up by crops from manure without litter during the year of its application.

Calculation of Liquid and Semiliquid Manure Without Litter. The amounts of liquid and semiliquid manure over the stabling period are calculated using the following formulas:

$$Semiliquid \ manure \ (\text{m}^3) = \frac{(feces + urine) \cdot S \cdot C}{1000}$$

$$Liquid \ manure \ (\text{m}^3) = \frac{(feces + urine + water) \cdot S \cdot C}{1000}$$

where (*feces + urine*) is the daily amount of animal excreta per livestock capita (see Table 3.11), (*feces + urine + water*) is the daily amount of animal excreta (plus water if it is used to dilute them) per livestock capita, S is the stabling period duration (days), C is livestock capita, and 1000 is the factor of conversion into cubic metres.

In the calculations, the weight of a cubic metre of liquid (diluted) manure can be taken equal to 0.95 ton and that of semiliquid (moderately diluted) manure, to 0.90 ton.

To establish the required volume of liquid manure storage facilities (in m³), it may be arbitrarily assumed that its daily yield is 40 to 55 litres (25-30 litres of feces + 10-15 litres of urine and 5-10 litres of water) per head of cattle and 10 to 12 litres per pig.

Application of Manure Without Litter. As has already been mentioned above, litter manure can be used only before sowing (during ploughing). Liquid and semiliquid manure, on the contrary, can be used as both preseeding and postseeding (dressing) fertilizer. In the former case, it can be ploughed under singly or together with chopped straw remaining in the field or with peat scattered in advance. After separation from the solid phase, the liquid fraction can be applied by sprinkling, while the solid fraction can be incorporated just as ordinary litter manure.

When the fields to be treated are limited in area or large amounts of manure without litter must be used, its percentage in the basal fertilizer may be much higher.

It can also be used in the preparation of peat-manure composts with a peat-to-manure ratio of 1:2 or 1:1. Because peat is deficient in phosphorus, shifting the ratio in its favour in such composts may lower their effectiveness. The percentage of phosphorus can be increased if ground phosphate rock (1-2%) is added to the compost.

The annual rates of undiluted manure without litter applied during cultivation may be as high as 35 t/ha for cereals, 40 to 60 t/ha in the case of potatoes, 60 to 80 t/ha for maize, and 80 to 90 t/ha in the case of fodder and sugar beets. The total annual rate of such manure applied to meadows and pastures or fields with perennial grasses may be 60 to 80 t/ha (10-15 t/ha if applied after each moving or grazing). However, to avoid excessive accumulation of nitrates in the green forage or fodder roots, the annual amounts of manure must contain no more than 70 to 100 kg nitrogen per hectare.

When used as preseeding fertilizer, manure without litter is applied to heavy soils throughout the warm season (in spring, summer, and autumn), while to light soils it is applied only in spring (spring crops) or in summer (winter crops) to avoid leaching of the nutrients. On pastures, manure without litter is used all the year round (even in winter over a thin layer of snow) on level ground. It should not be applied to areas inundated in spring or on slopes from which the fertilizer can be washed down during the spring thaw.

The USSR Ministry of Agriculture has recommended various systems for transporting and applying manure without litter to large farms and livestock breeding complexes (their selection depending on local conditions).

One of the systems has been recommended for farms without pipelines. It consists in that manure is reloaded from the enclosed storage facility at the farm into spreading cisterns, taken to the field, filled into field pits, and kept there till application time when manure is transferred from storage facilities (at the farm or in the field), into cisterns, then spread over the field surface and incorporated into the soil.

Another system is designed for farms equipped with pipelines and sprinklers. In this case, liquid manure is pumped through the pipelines from the storage facilities to the sprinklers. First, it is diluted with water (in a mixing

chamber) to a 1:8 or 1:10 ratio during the vegetation period and to a 1:1 or 1:3 ratio otherwise. Then, the field is treated with the aid of sprinklers.

A third system is also based on pipelines and resides in that manure without litter is pumped from the farm storage facility into the pit in the field with subsequent spreading from cisterns. Liquid manure is loaded into the cisterns or pumped through the pipeline over a distance of 300 m with the aid of a PNZh-250 loader. Special cisterns (RZhT-4, RZhT-8, and RZh-16) are used to carry and spread liquid manure.

Liquid manure is often separated into solid and liquid fractions. The solid fraction is applied by machines used to handle litter manure. The liquid fraction containing up to 90 per cent of nutrients of liquid manure is stored, then used to irrigate fields, meadows, and pastures.

To avoid ammonia nitrogen losses, the manure spread over the field surface must be immediately incorporated.

3.3 Manure Water

Manure, or dung, water is essentially overfermented urine of animals.

The quantity of manure water varies depending on how manure is stored. According to the USSR Research Institute of Fertilizers and Agronomical Soil Science, for example, four months of compact stacking yield 170 litres from 10 tons of the initial litter manure, the yields being 450 litres in the case of loose-compact stacking and 1000 litres for loose stacking (piling).

The quicker the decomposition of manure, the more water it produced. The total amount of manure water averages 10 to 15 per cent by weight of fresh manure. This figure does not take into account the part of the liquid that is absorbed and retained by litter.

The average nutrient contents in manure water are as follows: 0.25-0.30% N, 0.03-0.06% P_2O_5, and 0.4-0.5% K_2O.

Manure water is primarily a nitrogen-potassium fertilizer. All nutrients in it are in a readily available form, which is why it is considered to be a quick-acting fertilizer.

From the standpoint of nitrogen and potassium uptake (60-70%) by crops, manure water approaches inorganic fertilizers in effectiveness. Urobacteria rapidly convert the nitrogenous substances in manure water into ammonium carbonate which easily breaks down into carbon dioxide and ammonia.

A prerequisite for minimizing nitrogen losses from manure water is addition of enough litter, installation of manure tanks in barn- and manure yards, and addition of powdered superphosphate (3-5% by weight of manure water) to the liquid.

The reaction between the ammonia nitrogen of manure water and superphosphate yields salts resistant to decomposition:

$$Ca(H_2PO_4)_2 \cdot H_2O + 2CaSO_4 \cdot 2H_2O + 4NH_3 =$$
$$= 2(NH_4)_2SO_4 + Ca_3(PO_4)_2 \cdot H_2O + 2H_2O$$
$$Ca(H_2PO_4)_2 + NH_3 \quad NH_4H_2PO_4 + CaHPO_4$$
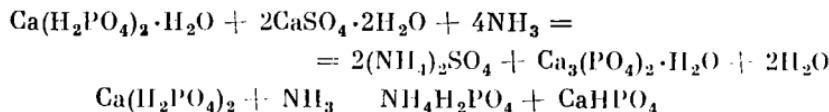
All phosphates settling on the manure tank bottom after the liquid has been used up should be applied as fertilizers (the best way being to compost them with organic fertilizers).

In barnyards without manure tanks but having peat, the latter should be used to fill sludge channels with new portions being added each time after the liquid is fully saturated with peat. One kilogram of low peat with a moisture content of 40 to 50 per cent may absorb about 2 kg of manure water, while the same amount of high peat may absorb up to 5 kg.

Manure water is used as fertilizer in its original form or composted with other organic fertilizers. In the former case, it is used as a basal fertilizer and for dressing. In both cases, nitrogen losses are avoided by incorporation of manure water immediately after it is spread over the soil surface. The basal application rate of manure water varies from 10 to 15 t/ha (10-20 t/ha when treating vegetables) depending on its quality and the crops to be treated.

To treat meadows and pastures, 10 to 20 t/ha of manure water are used. For dressing winter crops in spring, manure water should preferably be applied before harrowing.

Dressing machines are used to incorporate manure wa-

ter to a desired depth for treating row crops. When row crops are dressed for the first time, manure water should be incorporated along the row at a rate of 5 to 7 t/ha, and during the second dressing it should be incorporated in the middle between two rows at a rate of 8 to 10 t/ha.

It has been found that every ton of manure water increases crop yields (in terms of grain) by an average of one centner per hectare. Addition of superphosphate enhances the effectiveness of manure water perceptibly because it contains little phosphorus.

Manure water is most effective when composted with peat or other organic fertilizers.

3.4 Straw Used As Fertilizer

Straw contains an average of 0.5% N, 0.25% P_2O_5, and 0.8% K_2O. Sometimes, after farms satisfy their feed and litter requirements, some of the straw remains unused. Yet straw can be put to effective use as fertilizer if incorporated into the soil together with nitrogen (sometimes phosphorus) fertilizers or liquid manure.

Incorporation of the straw remaining in the field after harvesting (4-6 t/ha) eliminates the costs of transportation and labour, inevitable when straw is used as litter.

Application of straw as fertilizer boils down to the following.

The straw remaining in the field after harvesting is covered with manure without litter or nitrogen fertilizers (preferably ammonia or urea) spread at a rate of about 0.5-1.3% N per unit straw weight or 40-80 kg N per hectare. Phosphorus-deficient soils can also be treated additionally with phosphorus fertilizers.

After the fertilizers have been applied, straw is immediately incorporated into the soil by means of a topsoil plough to a depth of 5 to 7 cm. Two to three weeks later, when straw is already decomposed in the soil, autumn ploughing is carried out to the normal depth.

At large-scale livestock farms, liquid manure applied together with straw (40-50 t/ha) is preferable to nitrogen fertilizers. The above rates of nitrogen fertilizers recommended for incorporation together with straw have been calculated

to reduce the C:N ratio in the straw decomposing in the soil to a level ensuring its rapid mineralization without significantly reducing the content of available soil-derived nitrogen. Incorporation of straw alone, without nitrogen fertilizers, would sharply reduce the inorganic nitrogen content in the soil and crop yields.

Incorporation of straw should not be postponed till spring. Performing it in autumn is important in the sense that it will permit the phenolic compounds resulting from straw decomposition and toxic to crops to be leached from the soil more completely.

Experiments have shown that application of 5 to 10 t/ha of straw to late row crops together with nitrogen fertilizers often produces the same effect as manuring at usual rates. Straw is particularly recommended for treatment of leguminous crops.

3.5 Poultry Manure

Poultry manure is a valuable, more or less concentrated and quick-acting organic fertilizer. Just as ordinary manure, it contains all the basic nutrients necessary to crops but in much greater amounts (Table 3.16).

Table 3.16. Average Content of Water and Nutrients in the Dung of Various Poultry (% fw)

Poultry	H_2O	N	P_2O	K_2O	CaO	MgO	SO_3
Chickens	56	2.2	1.8	1.1	2.4	0.7	0.4
Ducks	60	0.8	1.5	0.5	1.7	0.3	0.3
Geese	80	0.6	0.5	0.9	0.6	0.3	1.1

The nutrient content in poultry manure varies widely depending on the composition of the poultry feed.

The amount of dung accumulated over a year is 6 to 7 kg from a chicken, 7 to 9 kg from a duck, and 10 to 12 kg from a goose.

All nutrients contained in poultry manure take the form of available compounds. Most of nitrogen in it is in the form of uric acid which turns, in storage, first to urea and then

to ammonium carbonate. Under unfavourable storage con-
ditions, the latter soon decomposes into ammonia, carbon
dioxide, and water, which may entail nitrogen losses.
When stored in large heaps, poultry dung soon becomes
heated, and ammonia evaporates more rapidly. Much nit-
rogen is lost as a result of cyclic freezing and thawing of
the heaped manure.

To eliminate (or minimize) these losses during accumula-
tion and storage of manure, it is recommended to add sys-
tematically 7 to 10 per cent by weight of powdered superphos-
phate, 20 to 40 per cent of dry peat powder, or 25 to 50
per cent of dry humus to it. It is even better if the poultry
house is bedded thickly with fine dry peat or shredded straw.
The bedding should preferably be done in a 25 to 30 cm
thick layer at first, then, as more manure is being accumu-
lated, peat should regularly (daily) be added at a rate of
10 to 15 g per chicken or 20 to 25 g per duck or goose. As
soon as the manure-impregnated bedding thickness reaches
0.5 to 1 m (nearly after half a year), it may be replaced.

At many poultry farms, sawdust is used for bedding. It
enables the poultry house to be kept clean. Yet it does not
decompose as readily as peat once incorporated into the
soil. In this connection, it is better to use hard-wood rather
than soft-wood sawdust (because the latter contains many
resinous substances). Manure on sawdust should better be
incorporated into the soil after lengthy (6 to 7 months)
composting.

Fresh poultry manure without bedding, which does not
yet contain ammonia nitrogen, can be rapidly dried at an
elevated temperature. The resulting dry dung contains
4-6% N, 2-3% P_2O_5, and 2-2.5% K_2O. It is easier to trans-
port than humid manure and can be stored for a long period
of time. It should be kept in dry storage.

Poultry manure is applied both before sowing and for
dressing. It is most valuable for flax, vegetables, fruit and
berry crops, potatoes, and fodder root crops.

Clean dry poultry manure is applied as a basal fertilizer
to vegetables and potatoes at a rate of 1 to 2 t/ha. The rate
of humid poultry manure applied in the same manner is 4
to 6 t/ha and, when applied with peat, 8 to 10 t/ha.

The rate of humid clean manure to dress various **crops**

is 8 to 10 centners per hectare, while the rate of its hole or furrow application is 4 to 6 centners. The rate of dry dung is half as high. For spray dressing humid manure should be diluted with water to one sixth or seventh of its original concentration.

3.6 Municipal Waste

Municipal waste includes various domestic garbage, paper, rags, dirt, dust, and ash. In terms of nutrients and fertilizing properties, municipal waste approaches manure. However, its decomposition rate in the soil depends on the ratio of its nutrients. For example, municipal waste with a large portion of domestic garbage and dust decomposes faster. Such waste can be used directly as fertilizer without composting. Waste with much paper, rags, and sawdust takes more time to decompose, and it should better be composted in advance.

In terms of dry matter, municipal waste contains an average of 0.6-0.7% N, 0.5-0.6% P_2O_5, and 0.6-0.8% K_2O.

In vegetable growing, waste is used as biological fuel in hothouses where it becomes a homogeneous, friable, and fully decomposed organic fertilizer which is then used to treat any crop.

When applied as a basal fertilizer, minicipal waste is incorporated into the soil well in advance (e.g. during autumn ploughing to treat spring crops). This is especially advisable in the case of uncomposted waste applied to heavy soils. The rates of uncomposted waste applied to various crops are the same as those of manure (20-60 t/ha). After waste has been composted or passed through hothouses, its rate is reduced to 15-20 t/ha.

Peat and Organic
Peat Fertilizers

4.1 Peat

Peat is the result of dying and partial decomposition of bog plants under conditions of excess moisture and lack of air. Any peat consists of non-humified plant residues, humus, and inorganic matter.

There is a great variety of peat types of different quality. Hence, its uses as fertilizer also vary. It is preferable to use peat for this purpose not in its original form, but as a component of different composts.

4.1.1 Composition and Properties of Various Types of Peat

Peat types are determined by the conditions under which it was formed, particularly the relief of peat bogs. They are also determined primarily by the constituent plant residues.

As regards the conditions of their formation, peat bogs (hence, the peat extracted from them) are divided into three types: high (upland), low (lowland), and transitional peats.

High peat was formed on raised ground from sphagnum mosses, cotton grass, ledum, and other plants with modest nutrient and moisture requirements.

Low peat owes its origin to low ground where its formation was governed by groundwater. It was formed from hypnum mosses, such grassy plants as sedges, reeds, reedgrasses, and horsetails, such woody plants as alder, birch, spruce, pine, willow, and other moisture-loving and nutrient-demanding plants.

Transitional peat occupies an intermediate position. Its lower layers are similar to low peat and the upper ones, to high peat.

The nomenclature of peat types depends on the peat-forming plants of which the partially decomposed residue con-

tent in peat is at least 20 per cent by weight of dry matter.

The agronomical classification of peats is based on their botanical composition, degree of decomposition, ash content, content of nutrients, acidity, and moisture capacity.

Botanical Composition. This is a predominant character of peat determining its quality in the context of agricultural chemistry. For example, high sphagnum peat is characterized by a low nutrient content, a low ash content, an acidic reaction, and a low degree of humification. Therefore, high sphagnum peat is not suitable for direct use as fertilizer. At the same time, by virture of its high moisture content and a capacity to absorb gaseous substances, sphagnum peat is a good material for litter. Peat containing residues of grasses, such as sedges and reeds, as well as woody plants is richer in ash elements and is characterized by a high degree of decomposition. Alder peat is richer in nitrogen because roots of this plant have nodules. It has a high degree of decomposition and can be used as fertilizer immediately after extraction and aeration even without being composted.

Important criteria in evaluating peat as a fertilizing material include the composition and ratio of various organic compounds in it. Such substances as lignin, bitumens, resins, waxes, and fatty acids present in peat are highly resistant to decomposition by microorganisms. Their high contents in peat are responsible for its slow decomposition. Proteinaceous and other nitrogen-containing organic substances lend themselves more readily to decomposition by microorganisms.

High sphagnum peat abounds in cellulose and hemicellulose (a total of 40%) and is extremely poor in humic substances (not more than 20%). It also contains sizable amounts of bitumens. Low sedge peat is rich in humic substances (about 50%) which are different in quality as compared to high peat. The humic substances of low peat are more closely associated with calcium than those of high peat.

Degree of Decomposition. Peat containing anywhere between 5 to 25 per cent of humified substances is referred to as *slightly decomposed* (young). It is recommended for use as litter then, after it has spent some time in a barnyard, as fertilizer in the form of peat manure.

Peat with a degree of decomposition ranging from 25 to

40 per cent is known as *moderately decomposed*. It should be used as fertilizer after composting.

If the degree of decomposition exceeds 40 per cent, we are dealing with *highly-decomposed* (lard) peat. It can be applied as fertilizer after extraction and aeration even without being composted but together with other organic and inorganic fertilizers. Moss peat of all three types (high, transitional, and low) is characterized by the lowest degree of decomposition (5-25%). Grassy peat has a higher degree of decomposition (20-40%), and woody peat, the highest (35-70%).

The degree of decomposition of peat is determined more accurately under a microscope and is expressed as percentage by weight of the decomposed peat portion. It can also be determined approximately from the peat appearance. Highly decomposed, or lard, peat is dark brown, almost black. When a lump of such peat is squeezed, it sticks to the hand, smears it, and passes through fingers. Slightly decomposed peat is light brown. Undecomposed fibres of plant residues are discernible in it by the naked eye. When squeezed, such peat does not pass through fingers and does not smear the hand (Table 4.1).

Table 4.1. Determination of the Degree of Peat Decomposition

State of plant residues	Plasticity of peat when squeezed	Characteristic properties of squeezed-out liquid	Degree of decomposition (%)
Well preserved and easily discernible	Does not pass through fingers and does not smear them	Easily squeezed out, colourless or slightly tinted, sometimes turbid	up to 20
Discernible under close inspection	Almost does not pass through fingers	Light brown, turbid	20-30
Difficult to see, traces of humus are visible	Partially passes through fingers, smears	Dark grey or dark brown, squeezed out dropwise with force	35-50
Almost invisible, pieces of bark may occur	Easily passes through fingers, smears perceptibly	Cannot be squeezed out	exceeding 50

Ash Content. Peat may have a normal or high ash content. In the former case, it contains up to 12 per cent ash and, in the latter, more than 12 per cent. High-ash peat belongs to the lowland type. If the agronomical properties of peat with a normal ash content depend primarily on its botanical composition, those of high-ash peat are determined by the chemical composition of the ash.

High peat contains up to 5 per cent ash, transitional peat contains 5 to 10 per cent, and low peat with a normal ash content, 8 to 12 per cent. Sometimes low peat contains 30 and more per cent ash. Such an ash content is in some cases due to sand and clay drifts or because they contain lime or vivianite. The high ash content due to clay and sand depreciates the value of peat as fertilizer because it is more costly to extract and transport.

Of greatest agronomical importance among the ash elements of peat are calcium and phosphorus. The degree of calcium saturation does not exceed 20 per cent of exchange capacity in high peat, 20 to 45 per cent in transitional peat, and 45 to 70 per cent in low peat with a normal ash content. Low peat is especially valuable because it contains lime or vivianite. Such peat can be used as fertilizer without composting.

When the lime (CaO) content exceeds 10% dw, peat can be used as a lime fertilizer. It is applied at a rate calculated from its lime content and soil acidity.

Peat containing more than 3% P_2O_5 is a good organophosphorus fertilizer. It is called vivianite peat. Its rate is calculated in terms of phosphorus.

Nutrient Content. Various types of peat differ in nutrient content. Just as manure, peat contains all the necessary nutrients but in a different ratio. Of the three basic nutrients (N, P, K), nitrogen is the most abundant in it (0.7-1.5% in the absolutely dry matter of high peat and 2.5-3.5% in low sedge peat). However, most of nitrogen in peat is in the organic form and becomes available to plants in the course of mineralization which proceeds at a much slower rate than decomposition of manure. The content of ammonia nitrogen (the only available form of nitrogen in peat) does not exceed 0.09 per cent in the dry matter of highly decomposed low sedge peat and 0.035 per cent in that of high peat. Therefore,

peat becomes a source of nitrogen for plant nutrition only through the medium of a biological agency, such as composting with manure, manure water, and fecal matter.

Peat with a normal ash content contains much less phosphorus than nitrogen. In the absolutely dry matter of peat, the phosphorus content varies from 0.05 (high peat) to 0.60 (low peat) per cent. Two thirds of this amount readily pass into a citric acid extract, hence, phosphorus in peat is in a more or less available form. More phosphorus is found in woody and low woody-sedge peat. Its high-ash variety contains more phosphorus, calcium, and iron but less nitrogen.

The potassium content in peat is low—0.05 to 0.2 per cent in the absolutely dry matter. Less than half of this amount is easily extractable from peat with water and is present in it in a readily available form. More than half of peat potassium is not available.

In general, peat with a normal ash content abounds in nitrogen, is poor in phosphorus and extremely poor in potassium as well as micronutrients (especially copper).

Acidity. The acidity of peat is an important indicator in defining the types and applications of peat in agriculture. For example, peat whose salt extract has pH below 5.5 is not suitable for use as fertilizer in its original form; it must first be used as litter in barnyards or composted with manure or lime, ash or ground phosphate rock. Top sphagnum peat is the most acidic, and low peat is the least acidic.

Moisture and Exchange Capacity. These properties of peat are of great importance, especially when it is used in litter. The highest moisture capacity is exhibited by high peat with a low degree of decomposition. In terms of absolutely dry matter, its moisture capacity is as high as 1000 to 1800 per cent as opposed to 500 to 1000 per cent in low peat. The exchange capacity of peat is much higher than that of the most humified soil and equals 100 to 200 meq (and even more) per 100 g of dry matter.

In general, the agrochemical properties of various peats with a normal ash content can be characterized as shown in Table 4.2.

High peat is characterized by a lower degree of decomposition, a higher acidity, and lower ash and nutrient contents.

Table 4.2. Agrochemical Properties of Peat with a Normal Ash Content

Peat	pH of extract		organic matter
	water	salt	
High	3.0-4.5	2.6-3.2	95-98
Transitional	4.0-6.0	3.6-4.4	90-95
Low	5.5-7.0	4.8-5.8	85-92

Low peat exhibits a lower degree of decomposition, a higher content of nitrogen and ash substances, and a lower acidity. Transitional peat has properties occupying an intermediate position between high and low peats; its upper layers are similar in properties to high peat, and the deeper layers, to low peat.

4.1.2 Agricultural Uses of Peat

Peat finds a great diversity of uses in agriculture. It is employed as litter, as a component of various composts, in peat-humus pots, in mulching, and sometimes directly as fertilizer applied together with inorganic ones. Using most peats as fertilizer in their primeval form is ineffective both agrochemically and economically.

Peat extraction begins with drainage of peat bogs, followed by freeing them of shrubs and tree stubs, removal of the top soddy layer, and excavation of peat layer by layer from the surface down after each layer has been loosened. The best time to do this is in summer. If the sod covering the peat is thin, the latter is loosened without being stripped of sod.

When peat is intended for use as litter, the peat bog surface may be rototilled, after which the loosened peat layer is turned to achieve the desired humidity. While peat is being dried, it is swathed or stacked.

In many cases, instead of being rototilled, the surface of a drained peat deposit is first ploughed with a brush breaker to a depth of 40 to 50 cm, which is followed by multiple disking. The top layer 6 to 8 cm thick is removed after drying and used as litter, in the preparation of composts, and

Content (% abs. dw)				
ash	N	P_2O_5	K_2O	CaO
2-5	0.7-1.5	0.05-0.15	0.05-0.10	0.2-0.4
5-10	1.2-2.5	0.10-0.25	0.10-0.15	0.4-2.0
8-15	2.5-3.5	0.20-0.60	0.15-0.20	2.0-6.0

so forth. Within a summer period, four to five such layers of loosened and dried peat can be taken (600-800 m³/ha).

Using Peat As Litter. Peat is an excellent material for litter. Its high moisture capacity ensures maximum absorption of liquid animal excreta, while its acidity and high exchange capacity permit ammonia nitrogen to be retained.

According to the state standard peat to be used as litter must have a degree of decomposition of up to 25 per cent, an ash content of up to 10 to 15 per cent, a moisture content of 50 per cent, and a content of wood particles (up to 60 mm in size) of up to 10 per cent. These requirements are best met by high sphagnum peat. Hypnum, sedge, and reed peats are less suitable for the purpose. Only young peats of the latter categories, with a degree of decomposition less than 20 per cent, are used.

Composting of Peat. This is one of the best ways to produce top-quality organic fertilizer. Recommended for composting is peat with a degree of decomposition exceeding 20 per cent, an ash content of up to 25 per cent, and a wood particle content of up to 10 per cent. Lime, ground phosphate rock, soluble inorganic fertilizers, or biologically active components (solid and liquid manure, fecal matter, etc.) are added to peat.

Peat with pH below 5, an ash content lower than 10 per cent, and a degree of decomposition ranging from 40 to 25 per cent is recommended for composting with lime, ground phosphate rocks, or ash. All types of peat can be composted with solid manure, liquid manure, fecal matter, and plant residues.

Preparation of Peat Compost Pots. In vegetable growing,

peat is used in the preparation of feeding plant blocks and
pots. The mixtures used contain various organic and earth
materials (peat, compost, humus, poultry manure, vegeta-
ble earth, silt), inorganic (nitrogen, phosphorus, potassium,
and micronutrient) fertilizers, and neutralizing additives
(lime).

Preferably, planting pots should be made of low or tran-
sitional peat with a neutral or weakly acidic reaction,
a degree of decomposition ranging from 30 to 40 per cent,
and an ash content of 3 to 15 per cent.

Peat used as Fertilizer Without Having Been Composted.
Suitable for this application is only lowland high-ash lard
peat rich in lime or phosphorus.

Used directly as fertilizer is, in particular, peat with pH
of its salt extract exceeding 5.5, an ash content exceeding
10 per cent (including CaO content above 4%), and a degree
of decomposition of at least 40 to 50 per cent. Especially
valuable in this respect are peaty tuffs as lime-organic
fertilizers and peat vivianites as phosphorus and organic
fertilizers. Application of peat and peat composts is par-
ticularly effective for light soils.

Peat intended for direct use as fertilizer is thoroughly aer-
ated after excavation. For peat to be properly aerated in
mechanized extraction (rototilling or ploughing with sub-
sequent multiple disking) takes a few days of dry weather.

Aeration is needed to drive off excess moisture from peat
and oxidize the monoxides it contains. Aerated low peat in-
corporated into the soil alone does not meet the nitrogen
requirements of plants within the first year. Peat with a nor-
mal ash content has little phosphorus and, especially, potas-
sium. Hence, in spite of the improved physicochemical prop-
erties of the soil, application of such peat without addition
of inorganic (primarily nitrogen) fertilizers fails to drasti-
cally increase the yield of the crop under treatment within
the first year.

In order to speed up the process of peat decomposition,
peat is incorporated into the soil together with a small
amount (5-10 t/ha) of solid manure, fecal matter, or manure
water.

If high rates of additive-free peat with a normal ash con-
tent have to be applied to produce a tangible effect (50-

90 t/ha), such additives permit the peat rate to be reduced to the usual manuring level. The application rates of peaty tuffs are determined from their lime content and those of vivianites, from the phosphorus content.

Peat Used As Mulch. Aerated peat in its original form is an excellent material for mulching, particularly in fruit, berry and vegetable growing. Peat is applied between rows to the surface and without incorporation, in a layer up to 5 cm thick. The purpose of mulching is to maintain better water, air, nutrient, and temperature regimes in the topsoil. Mulch is also used to prevent crusting of the soil and proliferation of weeds.

After the crop being mulched (for treatment either in the row middle or under trees) has been harvested, the peat used for mulching is ploughed under. For its speedier decomposition, it is advisable to add small amounts of solid manure, manure water, or fecal matter to the mulch being incorporated.

4.1.3 Exploitation of Drained Peat Bogs

Drained peat bogs can be used not only for extracting peat to be applied as fertilizer, but also for cultivation of farm crops. In some cases, this is done directly after appropriate reclamation without removing peat for fertilizing. In others, crops start being cultivated after partial removal of the upper peat layer for use as fertilizer, litter, or in composts.

It should be borne in mind, however, that the thicker the peat layer removed from the top, the less fertile the soil becomes and the more difficult it is to turn such peat bogs to highly productive farm fields. Therefore, the peat layer left *in situ* must be at least 50 cm thick.

All acid peaty soils being reclaimed must first of all be limed. According to the findings at the Belorussian Research Institute of Soil Science and Agrochemistry, peaty soils with the pH value of their salt extracts less than 5 and a degree of base saturation below 70 per cent must be limed (Table 4.3).

The lime rates (in terms of $CaCO_3$) for acid peaty soils must be calculated on the basis of half of their hydrolytic acidity

$(0.5 \ H_h)$:

$$\text{CaCO}_3(\text{t/ha}) = \frac{1.5 H_h \times 0.05 \times 10 \times d \times h \times 100\,000}{1000 \times 1000} =$$

$$= 0.5 H_h \times 0.05 \times d \times h$$

where 0.05 is the quantity of lime (in g/meq of hydrolytic soil acidity), 10 is a factor of conversion into 1 kg of soil, d

Table 4.3. Peaty Soil Groups According to Acidity and Liming Requirements

Peaty soil group according to acidity	pH in KCl	H_h (meq/100 g)	V (%)	Liming requirement
Too acidic	< 3.9	> 85	< 35	Acute
Highly acidic	3.9-4.3	85-70	35-50	High
Moderately acidic	4.3-4.7	70-50	50-60	Moderate
Weakly acidic	4.7-5.0	50-40	60-70	Low
Insignificantly or not acidic	> 5.0	< 40	> 70	None

is the volume weight of the soil (0.25, 0.3, or 0.4 for peaty soils), h is the ploughing depth (in cm), 100 000 is a factor of conversion into 1 hectare, and 1000 and 1000 (in the denominator) are factors of conversion of grams (CaCO_3) into tons.

At $H_h = 30$ meq/100 g of soil, a volume weight of 0.4 per cent, and a ploughing depth of 20 cm, the rate is $\text{CaCO}_3 = 0.5 \times 30 \times 0.05 \times 0.4 \times 20 = 6$ t/ha.

Peaty soils are characterized by a high organic matter content (up to 85-95%) and, consequently, high exchange capacity, high moisture capacity, high porosity, and low density (0.25-0.5). They also have a high total nitrogen content, low potassium content (except for peat bogs enriched with potassium-rich river silt), and low phosphorus content (except for low-level peaty bogs enriched with groundwater phosphorus). Fertilizer rates on peaty soils must be calculated with due account for the above characteristics.

Phosphorus-potassium fertilizers are most effective when applied to peaty soils, especially old ones. In such soils, particularly those in high and transitional bogs, nitrogen is pri-

marily in organic compounds that do not lend themselves easily to mineralization, within the first few years after reclamation. In addition, such soils are poor in microflora. Therefore, initially, when no intensive decomposition of organic substances in peaty soil takes place as yet, phosphorus-potassium fertilizers should be applied together with nitrogen ones. In this case, even when legume-grass mixtures are grown, complete fertilizer is of great importance (Table 4.4).

Table 4.4. Effect of Fertilizers on the Yield of a Pea-Oat Mixture Grown on Drained Peaty Soils Within the First Three Years of Reclamation (according to Kolmykov, 1974)

Experimental conditions	Forage yield (cent/ha)		
	1967	1968	1969
Background ($CaCO_3$ 10 t/ha)	35	35	43
Background $+ N_{40}P_{60}$	198	206	217
Background $+ N_{40}K_{60}$	165	161	183
Background $+ P_{60}K_{60}$	180	186	230
Background $+ N_{40}P_{60}K_{60}$	250	259	270

Application of nitrogen fertilizers to old peaty soils (some 10 years after their reclamation) produces little or no effect.

In view of the scant microflora in peaty soils, it is advisable to treat newly reclaimed areas with bacterial preparations or small amounts (5-8 t/ha) of manure, manure water, or fecal matter (rich in microflora) in order to accelerate the decomposition of organic substances.

Most peaty soils contain little micronutrients, especially copper. The requirements for copper (and other nutrients) can best be established by soil analysis. The maximum copper content in peat bogs is only 8 mg per kg of soil, while in some mineral soils it ranges from 20 to 100 mg per kg of dry soil.

The need in copper fertilizers arises when acid peat bogs contain less than 4 to 5 mg of copper and limed peat bogs, less than 6 to 7 mg of this nutrient per kg of soil. The copper deficiency in peat bogs stems from the fact that copper is

firmly bound in the organic matter of peat. Copper is applied to peaty soils in the form of blue vitriol (25 kg/ha) or sulphur waste (500 kg/ha), once every four to five years.

According to the Northern Research Institute of Hydraulic Engineering and Land Reclamation, integrated utilization of drained peat bogs is most promising for north-western regions of the RSFSR, abounding in peaty soils. It resides in that some parts of peat bogs are used for annual extraction of peat, removed layer by layer from the surface, to be used as fertilizer, whereas other parts are cultivated immediately in an established crop rotation program. Several years later, the first part with residual peat after layer-by-layer extraction is also used for crop cultivation.

4.2 Composts

Composting is one of the procedures aimed at accumulation of local organic fertilizers. It is necessary to retain (minimize losses of) nutrients in some organic fertilizers as they undergo decomposition (manure and manure water) and to enhance their availability in others (peat or another inert material).

More often than not compost consists of two basic components exhibiting dissimilar resistance to decomposition by microorganisms. One of them (peat, vegetable earth) performs the function of a water and ammonia absorber in the first place and does not decompose intensively without composting. The other component (fecal matter, manure water, etc.) is rich in microflora and contains sufficient amounts of easily decomposable nitrogenous organics. In such composts, the first component is prevalent (peat). The second component is taken in smaller amounts (sometimes 10-15% by weight of the total compost) and with the only purpose of activating the microbiological processes of organic matter decomposition. Such composting is called biological. It ensures accumulation of large quantities of a high-quality organic fertilizer by adding more inert materials whose fertilizing values is insignificant. This group includes peat-manure, peat-fecal, and peat-manure water composts comprising straw and other poorly decomposable organic materials with fecal matter, manure water, and the like. Organic com-

posts may also incorporate microflora in the form of bacterial preparations.

Also important is composting of some organic fertilizers with inorganic ones and lime. It is intended to enrich organic fertilizers with deficient nutrients and neutralize their acidity which inhibits the development of microorganisms. This category includes manure-phosphorite, peat-phosphorite, peat-manure-phosphorite, peat-lime, peat-ash, enriched peat and other composts.

In some regions, peat is composted with liquid ammonia and inorganic fertilizers (peat-inorganic ammonia fertilizers).

In addition to manure and peat, straw as well as other waste and refuse are used in composting. The purpose of this procedure is to let waste and refuse decompose to such a degree as to transform their constituent nutrients to an available form and to rule out or minimize the possibility of biological nitrogen fixation in the soil after their incorporation.

Calculations made at the Ukrainian Research Institute of Economics indicate that, when manure and peat-manure composts are hauled at a distance of 4 km to be applied to potatoes and maize, the yield increase expressed in state purchasing prices is more than twice the cost of preparation, transportation, and application of these fertilizers. When the length of their transportation doubles, the expenses involved grow but are still compensated by the crop return. If the aftereffect of manure and peat-manure composts is taken into consideration, the economic return is even higher. According to the findings at the same institute, application of peat alone was economically ineffective when it was transported to a distance of not only 8 but even 4 km.

Peat-Manure Composts. These are the most widely used composts. Their preparation, just as that of peat manure, is one of the most effective ways to accumulate a high-quality organic fertilizer. Peat manure and peat-manure composts are produced differently. If peat manure results from use of peat as litter, peat-manure compost is obtained by mixing peat and manure while stacking them or directly on a peat bog.

Under the effect of manure, peat nitrogen soon becomes more mobile and available. Manure also reduces the acidity of peat and creates more favourable conditions for the activ-

ity of the microorganisms involved in the decomposition of organic (including nitrogenous) substances. On the other hand, peat as a material with high moisture and exchange capacities effectively retains both the liquid matter and ammonia nitrogen released on decomposition of manure, whereby their losses are curtailed.

All three peat types are suitable for composting with manure, the best being aerated manure whose moisture content
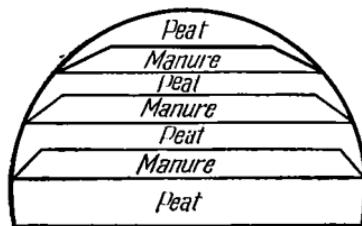
Fig. 4.1. Composting of manure and peat in layers

does not exceed 65 to 70 per cent. It is extracted in summer by layerwise stripping of the peat bog surface.

The manure to peat ratio in such composts depends on the availability of these components at farms, their quality, and the season. For example, this ratio may be 1 : 1 in winter and 1 : 3 in summer.

There are two main techniques of composting manure and peat in stacks: in layers and centred.

Composting in Layers. In stacks 4 to 5 m wide, layers of peat are alternated with those of manure (Figure 4.1). First, a peat layer up to 50 cm thick is placed over the entire width and length of the stack to prevent manure water from seeping into the ground. Then, a layer of manure is placed on top. Peat and manure layers are alternated in this manner till the stack reaches 1.5 to 2 m in height. The topmost layer must be of peat to minimize volatilization of ammonia nitrogen from manure. The thickness of individual layers depends on the manure to peat ratio in the compost. For instance, at a ratio of 1:1, the manure and peat layers in a stack may be 25 to 30 cm thick. The more peat is used, the thicker its layers must be as compared to manure.

Centred Composting. Manure is placed in one or several heaps in the centre of a peat stack. In this case, a layer of peat

50 to 60 cm thick is placed at first, followed by a manure layer 70 to 80 cm thick and 1 to 1.5 m narrower than the underlying peat layer, placed along the stack in its centre. If manure is not sufficient or liquid manure without litter is used, it should be placed inside the peat stack in the form of separate heaps. Once in place, manure is covered on top and on all sides with a peat layer 50 to 70 cm thick (Fig. 4.2).

Centred composting of manure and peat is ideal for regions with cold winter (winter composting) when the stack may
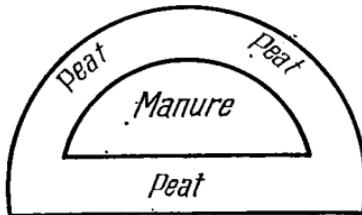
Fig. 4.2. Centred composting of manure and peat

freeze through. With this type of composting, the temperature inside the stack does not go below 25 to 30 °C throughout the winter. Manure and composts must be stacked in winter within one or two days, preferably during thaw.

Stacking of Peat-Manure Compost in the Field Using a Bulldozer. In summer, a bulldozer is used to stack peat-manure compost. In this case, peat is hauled into the field to be manured in dump trucks and tractor trailers and piled in a row 5 m apart. Then, manure is brought in and dumped between the piles of peat. Three such rows are built on a site. After that, the bulldozer pushes the two extreme rows towards the one in the middle, the entire mass is mixed in two opposite directions, and a stack is formed.

Regardless of whether layered or centred composting is performed, the stack is stirred by agitators or a bulldozer at least once during the storage period to ensure uniformity of the compost.

When peat-manure compost is stacked by means of a bulldozer, no additional stirring is required.

Peat-manure compost stacks need not be compacted. Loose stacking of such compost speeds up the decomposition of

organic substances almost without any losses of ammonia nitrogen from manure (it is absorbed by peat).

In summer, to avoid desiccation of the stack, it should be periodically sprinkled with manure water or (if it is not available) plain water.

Higher quality peat-manure composts are obtained by adding ground phosphorite rock during stacking (15-30 kg per ton of the composted material).

Ground phosphate rock is spread over each layer of manure and peat during stacking. Its distribution throughout the compost is more even when manure and peat are composted in layers. This is how peat-manure-phosphorite composts are prepared. Even at a manure content from 30 to 50 per cent, such composts are as effective as well prepared manure.

In some cases, added to such composts apart from phosphorus fertilizers are potassium ones at a rate of 5 to 6 kg per ton of peat as well as lime (according to peat acidity). Potassium fertilizers and lime are added to the peat layer, while ground phosphate rock is added to manure layers.

Peat is composted with liquid manure in the same manner as with manure water.

Peat-Manure Water Composts. The manure water accumulated in tanks should be composted with various types of peat with the exception of calcareous peat because composting with the latter entails sizable losses of ammonia nitrogen from manure water.

In winter, peat-manure water composts are prepared in the manure yard and, in summer, this is done in field stacks or directly on drained peat bogs.

To prepare peat-manure water composts, 0.5 to 1 t of manure water is taken per ton of aerated peat, depending on its moisture content. There are two ways in which peat is composted with manure water. Firstly, peat is stacked alone to a width of 3 to 4 m and a height of 1.5 to 2 m, then a trough is depressed on top in the middle of the stack, 50 to 80 cm deep and about 1 m wide, which is filled with the necessary quantity of manure water. After the latter has been fully absorbed, the trough is covered with peat, and the stack surface is smoothed out (Fig. 4.3). Secondly, peat is stacked in layers 30 to 50 cm thick to a height of 1.5 to 2 m. and each layer, except for the topmost one, is impregnated

with manure water. The best procedure is to place every new peat layer after the previous one has become heated, which happens on the fourth or fifth day after impregnation with manure water.

A better quality compost can be produced by adding ground phosphate rock (1.5-2% by weight of peat) before impregnating peat with manure water. The result is known as
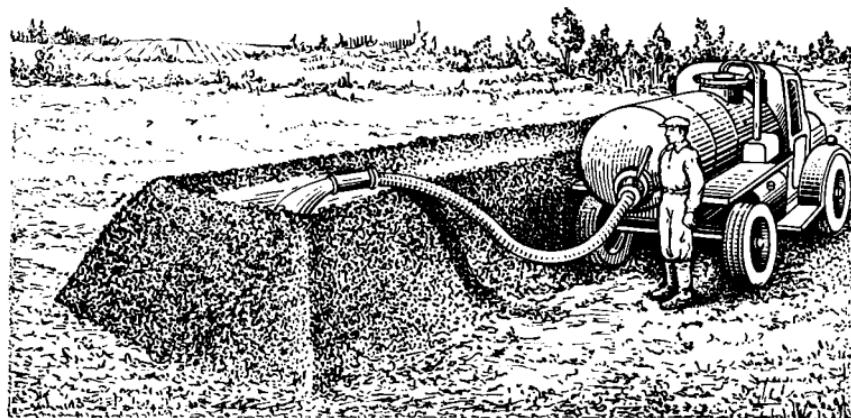

Fig. 4.3. Preparation of peat-manure water compost

peat—manure water—phosphorite composts enriched with microorganisms, mobile nitrogen, and potassium derived from manure water, phosphorus and calcium derived from the fertilizer.

Depending on the properties of the composted material and the season, peat-manure water composts mature within one to four months. During this period, other microbiological processes in compost stacks are accompanied by nitrification. The weakly alkaline reaction (pH 7-8) of peat-manure water composts, their abundance in carbohydrates, and lack of oxygen are also responsible for the denitrification that follows. The more vigorous the nitrification in stacks, the greater the danger of nitrogen loss due to the subsequent denitrification. According to the USSR Research Institute of Fertilizers and Agronomical Soil Science, when peat-manure water composts are stacked loosely, more nitrogen is lost

than from compact stacks in which more ammonia nitrogen is retained.

It takes a month or two for nitrates to form in compact stacks. Hence, no denitrification can occur during this period.

Peat-manure water composts should preferably be incorporated into the soil before this period expires.

Fecal Matter and Fecal Composts. The fecal matter in cesspits contains an average of 0.5-0.8% N, 0.2-0.4% P_2O_5, and 0.2-0.3% K_2O.

All these nutrients are much more readily available than in other organic fertilizers (except for manure water from which nutrients are easily taken up by crops). Therefore, fecal matter belongs to quick-acting organic fertilizers. 70 to 80 per cent of its nitrogen is in ammonia and urea.

At present, fecal matter is used as fertilizer dried or diluted with water. The dried and powdered fertilizer is known under the name of **powderette**. It contains about 2% N, 4% P_2O_5, and 2% K_2O. However, the lengthy process of drying involves heavy nitrogen losses (in the form of ammonia). To cut down these drying losses, it is recommended to add dry peat powder (8-10%) or powdered superphosphate (3-5%) to fecal matter.

Powderettes can be applied at a rate of 2 to 3 t/ha. During the year of their application, plants take up from them 50-60% N, 30-40% P_2O_5, and 60-70% K_2O.

Municipal fecal matter is usually disposed of in a highly diluted state through the sewer system, in the form of domestic sewage. Its application to irrigated fields is one of the effective ways to use fecal matter as fertilizer. In this case, plants are supplied with water and all the necessary nutrients simultaneously.

One cubic metre of sewage contains an average of 60-100 g N, 10-20 g P_2O_5, 20-40 g K_2O, 60-110 g CaO, 25-50 g MgO, and 60-70 g Cl. It can be seen that sewage contains relatively large amounts of nitrogen. Therefore, it is highly effective when used for treatment of ensilage and other crops characterized by increased nitrogen requirements. Fecal matter contains much chlorine, which makes it ill suited for treatment of tobacco, potatoes, and berry crops responding negatively to chlorine in the nutrient medium.

From the sanitary and agronomical standpoints, fecal matter should better be used in composts. The composting of fecal matter with peat, straw, and other poorly decomposable organic materials gives high-quality organic fertilizers. This is the best way to preclude nitrogen losses from fecal matter and to disinfect it. Within the first two to three months after the compost is initiated, all pathogens in it die off and the unpleasant odour disappears completely.

Peat-Fecal Compost. This compost is the most effective (and quick-acting) organic fertilizer. All types of peat are suitable for composting with fecal matter, which is taken in amounts depending on the moisture content and degree of decomposition of the peat. The higher its moisture content and degree of decomposition, the less fecal matter is required for composting. For example, one ton of low peat with a moisture content of about 70 per cent requires half a ton of fecal matter. When fresh, properly aerated moss peat of the same moisture content is used, the amount of fecal matter can be increased to two tons and, at a moisture content of about 50 per cent, three and a half tons per ton of peat.

Peat-fecal compost is kept in loose piles for some time to disinfect the fecal matter.

Peat-fecal composts are prepared in the same fashion as peat-manure water ones. The process of peat and fecal matter composting is fully mechanized. For example, in centred composting, a peat stack up to 2 m in height is put together by a bulldozer. The latter is also used to form a depression in the middle of the stack and to cover it with crushed peat after the depression has been filled with fecal matter. After a month or so, the compost is mixed by means of a bulldozer to obtain a uniform mass.

When the composting is done in layers, every peat layer is topped with fecal matter brought in by a tank truck.

Peat-Mineral Composts. *Peat-Lime and Peat-Ash Composts.* Acid peat (salt extract pH < 5) is always composted with lime or ash interspersed with each peat layer 15 to 20 cm thick during stacking. The most suitable lime fertilizer for this purpose is dolomitic meal.

When peat is composted with lime, its acidity is neutralized and it becomes enriched with calcium and, sometimes, magnesium. The amount of lime in such composting should

be matched with one eighth of hydrolytic acidity of the
peat. At a moisture content of 60 to 70 per cent in the peat,
lime accounts for one to three per cent of its weight (the more
acidic the peat, the more lime is used in composting).

Peat-lime composts mature within four to five months.
They are rich in calcium but poor in potassium and phospho-
rus. This is why they must be applied together with phospho-
rus-potassium   fertilizers.

The purpose of composting peat with ash is to enrich it
with calcium, phosphorus, and potassium, as well as to re-
duce its acidity. Taken per ton of aerated peat are 25 to
50 kg of straw or wood ash, or even 100 to 200 kg of peat ash.

Peat-Phosphorite Composts. Composting peat with ground
phosphate rock is an important way to enhance the effec-
tiveness of these fertilizers. Here, peat is enriched with phos-
phorus and calcium from ground phosphate rock, and its
acidity is mitigated somewhat (although to a lesser extent as
compared to composting with lime and ash). The acidity of
peat renders the phosphorus of ground phosphate rock more
readily available to plants. It has been established that it
takes only a month of composting for 30 to 60% P_2O_5 from
ground phosphate rock to become available.

More suitable for composting with ground phosphate rock
is acid peat but containing no mobile aluminium. Each ton
of peat with a moisture content of 65 to 70 per cent requires
10 to 30 kg of ground phosphate rock. It is added to peat dur-
ing stacking or directly on the drained peat bog during its
extraction in layers from the surface. It takes two to three
months for peat-phosphorite composts to mature.

Peat-phosphorite composts are effective on all soils, espe-
cially those where ground phosphate rock placed alone has
little effect (sandy and sandy loam, limed soddy podsolic or
neutral and alkaline soils).

Peat-lime and peat-phosphorite composts should better
be applied in combination with nitrogen fertilizers because
during the first year they cannot meet the requirements of
crops for available nitrogen.

Enriched Peat Composts. Their preparation calls for in-
creased amounts of ground phosphate rock plus ammonium ni-
trate. For every 100 kg of absolutely dry peat, 30 kg of ground
phosphate rock and 8 kg of ammonium nitrate are taken,

whereby the total phosphorus content in it is brought up to
6-7.5 per cent and that of total nitrogen, to 4-5 per cent.
At a moisture content of about 75 per cent in peat, each ton
of it requires about 75 kg of ground phosphate rock and 20
kg of ammonium nitrate (the phosphorus content in the or-
ganic fertilizer being brought up to 1.5-2% and that of ni-
trogen, up to 1%). Enriched composts mature within a month
or a month and a half.

Peat-Mineral Ammonia Fertilizers. These fertilizers are
produced by saturating peat with aqua ammonia (matched
with a hydrolytic acidity value of 0.7 for low peat and 1.0
for high peat) with addition of phosphorus and potassium
fertilizers. The most suitable peat for this purpose has an
ash content of not more than 25 per cent, a moisture content
of 55 to 65 per cent, and a degree of decomposition of 15
to 20 (in the case of low peat) or 20 to 25 (in the case of high
peat) per cent. Peat-mineral-ammonia fertilizers receive 30
to 35 kg of phosphorus fertilizers (ground phosphate rock or
a mixture of superphosphate with equal amounts of ground
phosphate rock), 10 to 12 kg of potassium chloride (or an
equivalent amount of some other potassium fertilizer), and
30 to 35 litres of 25% aqua ammonia per ton of dry high
peat. When low peat is used, the amount of phosphorus
fertilizers is reduced to 20-25 kg, potassium chloride to
6-8 kg, and aqua ammonia to 20-25 litres.

Composting of Peat on Drained Bogs. When peat bogs are
not far from the fields to be fertilized, it is best to compost
peat at its source. This considerably cuts down the cost of
transportation and composting. Composting in this case
resides in that the tillage and loosening of the peat bog sur-
face are combined with addition of ground phosphate rock,
lime, manure, manure water or fecal matter with subsequent
stacking of the resulting mixture. In some instances, the
tillage of a peat bog is combined with cultivation of leg-
umes, ploughing down of all grown plants or only their resi-
dues, and stacking of the peat-legume mass.

The entire process of composting on peat bogs, including
drainage, comprises the following sequential opera-
tions:

drainage of the bog by digging trenches with the aid of
crawler-mounted trenchers, ditchers, and other machines;

removal of scrubs, stumps, and other vegetation with the aid of scrub slashers, grubbers, and scrub rakes;

tillage of the drained bog rid of stumps and scrubs with the aid of a tractor plough to a depth of 25 to 30 cm, followed by harrowing (once or several times);

spreading of manure, fecal matter, ground phosphate rock, or other compost components at rates calculated for a peat extraction cycle (removal of the top layer 5 to 10 cm thick);

incorporation of fertilizers with the aid of a disc harrow and multiple turning of the top peat layer with the aid of cultivators so as to bring the moisture content of this layer to 60 per cent;

swathing of the peat mixture from the dried top layer, followed by stacking with the aid of a bulldozer.

All of the above-described peat composts, including peat-green manure ones, can be prepared on peat bogs. Calculations of the quantity of the compost to be prepared are based on the fact that, at a peat removal depth of 20 cm and with a cubic metre of peat weighing about 400 kg, every hectare of the bog area yields about 800 tons of peat per season. The rates of organic and inorganic fertilizers applied to peat bogs are determined from such calculations.

Peat-Green Manure Composts. By definition, these are composts resulting from cultivation of leguminous plants on peat bogs with their subsequent ploughdown. The latter operation involves either all of the grown plants (e.g. alkaloidal lupine) or only root and afterharvesting residues after the above-ground mass has been used as fodder (fodder lupines and other legumes). In the former case, peat-green manure compost is obtained. Such composting enriches peat with fresh, easily decomposable vegetable matter as well as phosphorus and potassium, which are incorporated at increased rates before seeding the legumes. For legumes to be sown on a drained peat bog, it has to be ploughed in autumn. If the peat is acidic, lime is applied during ploughing to match one half of its hydrolytic acidity. During disking in spring, one to two tons of ground phosphate rock and three to four centners of potassium chloride are incorporated. After the plot is packed with a heavy roller, leguminous seeds treated with nitragin are sown.

When legumes are grown as fodder, the above-ground mass is browsed by cattle or mown, then the plot is tilled.

When green manure crops are grown, the vegetable mass is rolled down at the flowering stage, shredded, and ploughed down to a depth of 15 cm. 15 to 20 days later, the peat bog surface is disked, and the peat-legume mixture is swathed to a height of 1.5 to 2 m and left in swaths for one or two months.

Peat-green manure composts are as effective as half-decomposed manure and applied at the same rates as manure.

Green Manure

Green manure is plant material ploughed down into the soil while green to enrich it with organic matter and nitrogen. Green manure crops include primarily leguminous plants (lupine, seradella, sweetclover, winter vetch, milk vetch, peavine, sainfoin, etc.).

In some cases, nonlegumes (mustard, buckwheat) or legume-grass mixtures are used as green manure. However, sizable amounts of nitrogen are accumulated in the soil only after manuring with legumes.

Importance of Green Manure. Just as any other organic fertilizer, green manure produces a manifold positive effect on soil properties and crop yields.

First of all, green manure enriches the soil with organic matter and nitrogen. Depending on manuring conditions, one hectare of arable land often receives 35 to 45 tons of fresh organic matter containing 150 to 200 kg of nitrogen fixed from air by nodule bacteria (when leguminous green manure crops are sown).

Incorporation of green manure into the topsoil leads to accumulation of nitrogen and other nutrients. All ash elements present in green manure are extracted by the roots of legumes during their vegetation period not only from the topsoil, but also from deeper horizons. Ash elements are said to be pumped from lower to upper soil levels. Green manure contains almost the same (and even greater) amount of nitrogen as manure does, although its phosphorus and potassium contents are lower (Table 5.1).

The low contents of phosphorus and potassium in green manure can be compensated by incorporation of phosphorus and potassium fertilizers immediately after or during manuring.

The factor of utilization of green manure nitrogen by plants (during the first year of incorporation) is almost twice as

Table 5.1. Percentage Content of Basic Nutrients in Green and Ordinary Manure (according to Alekseev)

Fertilizer	N	P_2O_5	K_2O	CaO
Mixed manure (compact storage)	0.50	0.24	0.55	0.70
Green manure (lupine)	0.45	0.10	0.17	0.47
Green manure (sweetclover)	0.77	0.05	0.19	0.97

high as that of manure nitrogen. Incorporation of green manure does not entail any losses of the nitrogen accumulated in it, whereas in the case of ordinary manure it is extremely difficult to avoid losses in storage, transportation, and application. Green manure decomposes in the soil much quicker than other cellulose-rich organic fertilizers.

Just as other organic fertilizers ploughed down into the soil, green manure slightly reduces its acidity, restricts the mobility of aluminium, increases the buffering, exchange and moisture capacities of the soil, improves its water permeability and structure. Green manure strongly activates soil microorganisms. The microbiological processes in the soil are intensified significantly already during growth and development of green manure crops. It is precisely in this period that nodule bacteria become more active. The conditions for soil microflora are improved further after green manure is ploughed down.

Decomposition of the incorporated green manure enriches soil and surface air with carbon dioxide.

Green manure is a major factor of increasing the fertility of poorly cultivated (especially sandy and sandy loam) soils. It must be used first of all in regions where organic fertilizers are in an extremely short supply or where their transportation is difficult. Ploughdown of green manure crops in the same field where they are grown eliminates the need of its transportation. This permits green manure to be used with success in combination with inorganic fertilizers for developing the soil in remote parts of fields or on mountain slopes, the organic fertilizers that are difficult to transport (i.e. manure, peat, and composts) being applied at heavier rates to

the nearest fields (primarily in farm and vegetable crop rotations), thereby drastically cutting down the expenses involved in the transportation of organic fertilizers.

5.1 Green Manure Cropping and Forms

Depending on whether green manure crops are cultivated alone or in combination with other crops, distinction is made between *independent* and *companion* (or *mixed*) green manure cropping.

In the former case, green manure crops occupy a field for one or two seasons or even several years. These crops normally occupy fields for a relatively short period of time, for example, in some subtropical regions, between harvesting of one crop and sowing of the next. Such cropping is referred to as intermediate.

Mixed cropping, or intercropping, implies growing a main crop on a field together with a green manure crop or growing the latter between rows of another crop. This permits a large quantity of green material to be obtained already during growth and development of the main crop. Green manure crops are ploughed down immediately or soon after the main crop has been harvested.

Another distinction depending on whether green manure crops occupy the entire field or separate strips is between *solid* and *strip* cropping.

In strip cropping, strips of various width are alternated, some of them being occupied by green manure crops and the strips in between being not, so that the plant material of one strip is used to fertilize the one next to it. Strip cropping is exemplified by planting of green manure crops between rows in orchards, tea and citrus plantations. It is also practised on mountain slopes (with strips extending across the slope) to control soil erosion (sundial lupine, milk vetch, alfalfa, clover, etc.). Sometimes, green manure crops are planted solidly, then strips are made. For instance, when sandy soils in the Non-Black Earth zone are developed, a field is sown solidly with sundial lupine for the first few years, then ploughed up in such a manner that tilled strips alternate with untilled ones. Over the following years, the tilled strips

are occupied by food and fodder crops and fertilized with the mown lupine from the other strips.

Depending on when green manure crops are sown—before or after harvesting of the preceding main crop, they are divided into *subordinate* and *stubble* ones. In the former case, green manure crops (lupine, sweetclover, seradella, etc.) are sown under the preceding main crop, and in the latter, they (annual lupine, pea, etc.) are sown immediately after the main crop has been harvested.

In regions where the time interval between harvesting of the preceding crop and sowing of the second main crop (to be fertilized) is too short to grow green manure crops in sufficient quantities or where the climatic conditions are not favourable for the development of green manure crops early in their vegetation period, it is better to resort to subordinate cropping. In regions with warm, humid and long autumns, stubble crops intended for fertilizing sugar beet, fodder root crops, maize, and wheat can be grown successfully.

In the irrigated regions of Central Asia and humid subtropics of the Transcaucasian coast of the Black Sea, autumn, or prewinter, green manure crops are common. They are sown in September or October and ploughed down the next spring. Depending on local conditions, the crops sown in autumn may be subordinate or stubble.

There is also a variety of ways how to apply the grown green manure crops. Used as green manure is either the entire plant material (including the above-ground parts and roots) or only part of it. In this respect, three basic forms of green manure are distinguished: complete, mown, and aftermath.

Green manure is said to be complete when the entire plant material is ploughed down.

It is defined as mown when incorporated into the soil are only the above-ground parts of green manure crops grown elsewhere and brought to the field to be treated after they have been mown.

Aftermath green manure implies ploughing down of stubble and root residues of plants after the aftermath has reached a certain height (e.g. ploughdown of the stubble with aftergrowth following mowing and utilization of the green material of sundial lupine, annual fodder lupine, seradella, sweetclover, clover, or other legumes).

5.2 Areas of Green Manure Application

The vastest area where green manure produces good results is the Non-Black Earth zone with its soddy podsolic soils poor in humus and mobile nutrients. The role of green manure in the development of sandy and sandy loam soils of this area is especially important. In the European part of the Non-Black Earth zone, all basic forms of green manure (complete, mown, aftermath, or combined) can find broad application for independent or mixed subordinate or stubble cropping (involving lupine primarily).

Ideally suited for Siberia are such independent green manure crops as annual and sundial lupine (on soddy podsolic soils) or sweetclover (on moderately and weakly alkaline soils).

Green manure has also been gaining in importance in the Far Eastern regions characterized by abundance of warmth and moisture but having humus-poor soils. The most important green manure crops in these regions include annual (blue) and sundial lupine.

In irrigation farming, relatively early springs and late autumns, warm and sunny weather, and artificial watering favour rapid growth of green manure crops producing high yields and used successfully as fertilizer.

In regions of irrigated cotton growing (Central Asia and Transcaucasia), soils (mainly sierozems) contain little humus and, therefore, require large amounts of organic fertilizers. Yet the possibilities of their accumulation are limited there. The green manure crops grown in these regions include winter pea (planted before winter, in August or September, or as a second crop, in July or August), winter vetch and crimson clover (planted between cotton rows in August), peavine, mung bean, and cow pea.

The green manure crops grown in irrigation farming regions (Volga Region, Rostov Region, Krasnodar Territory, the Crimea, and southern Ukraine) include annual white sweetclover, vetch, peavine, and trigonella.

Data supplied from the Yershov experimental field (Saratov Region) indicate that the best green manure crops on dark chestnut soils and southern chernozems are trigonella and vetch-oat mixture, while the best subordinate crop is annual white sweetclover.

In regions of irrigation farming, green manure crops should preferably be sown immediately after harvesting of other crops (stubble crops) or in spring, under the nurse crop such as spring wheat (subordinate crops). In the former case, green manure crops (vetch-oat mixture, peavine, or trigonella) are sown after harvesting of the preceding crops or after the field has been watered, then ploughed down in autumn or early spring. In the latter, they (e.g. subordinate sweetclover) continue to grow on the same plot after harvesting of the nurse crop and ploughed down in autumn.

5.3 Growing and Application of Some Green Manure Crops

The most widely grown green manure crops include lupine, seradella, and sweetclover.

Lupine. Grown in the Non-Black Earth zone are both annual and perennial (sundial) lupines with different alkaloid contents. Alkaloidal lupine is grown only for use as fertilizer, whereas alkaloid-free (sweet) lupine has different uses: the above-ground parts are used as fodder, while roots with afterharvesting residues are used as fertilizer. The major areas where lupine is grown are Belorussia, the Ukraine, and the Non-Black Earth zone of the RSFSR.

All varieties of lupine yield a lot of vegetable matter and accumulate much nitrogen even on the poorest sandy soils. The highly developed roots of lupine are capable of easily dissolving unavailable phosphates from the soil and fertilizers. This makes it possible to treat lupine with ground phosphate rock whose phosphorus becomes available to all subsequent farm crops grown in the same field.

As a vigorous nitrogen-gatherer, lupine can meet not only its own nitrogen requirements, but also those of the cereal in mixed cropping. Therefore, such crops do not need nitrogen fertilizers but respond well to phosphorus and potassium ones. Application of phosphorus fertilizers to lupine is particularly important early in its growth on limed soils when its roots are not yet capable of extracting enough phosphates from the soil. Phosphorus and potassium fertilizers are to be applied to lupine before seeding.

Unlike other legumes, lupine thrives on acid soils. In some cases, annual lupine is intolerant to liming. Sundial lupine responds negatively to liming only at the very beginning of its development. Experiments have shown that one of the reasons why lupine is inhibited on freshly limed soils is the deterioration of phosphate nutrition during the first vegetation period. Lime incorporated into an acid soil does not allow lupine to take up the phosphorus from poorly soluble soil phosphates and fertilizers. Phosphorus from the ground phosphate rock applied together with lime is taken up by lupine either in insignificant amounts or not at all within the first few months of its development.

Hence, when lupine is grown on freshly limed soils, the best phosphorus fertilizer is pelletized superphosphate applied at least in small amounts at seeding. Otherwise, the major phosphorus fertilizer for all varieties of lupine is ground phosphate rock.

In order to develop soddy podsolic soils, lime and ground phosphate rock are applied to lupine at the same time but to different depths of the arable layer: lime is incorporated deeper, under plough with a jointer, while ground phosphate rock is placed above, during preseeding cultivation.

Such layerwise application of lime and ground phosphate rock to lupine as well as placement of potassium fertilizers with subsequent incorporation of green manure enrich the soil with organic matter, nitrogen, phosphorus, potassium, and calcium and neutralize excess soil acidity. All this creates ideal conditions for high yields of grain and row crops even on the least fertile sandy and sandy loam acid soddy podsolic soils.

Annual Alkaloidal Lupine. The most suitable green manure crops for the northern part of the Non-Black Earth zone are blue (*Lupinus angustifolius* and yellow (*Lupinus luteus*) lupines.

Annual lupine is grown independently and mixed with other crops. It is planted on fallow to fertilize winter grain crops or in fields after early-maturing crops (as a stubble or subordinate crop) to be ploughed under spring crops (during autumn ploughing).

The best time to plough down annual lupine is when pods are formed on its main stem. It is precisely then that lupine

accumulates the maximum amount of nitrogen. If it is ploughed down later, its fertilizing value decreases because of the increased cellulose content. Lupine grown on fallow is ploughed down not later than two to three weeks before winter crops are sown. This period of time is required for the soil to subside so as not to expose the tillering nodes of the sown winter crops after their sprouting.

Before lupine (annual or perennial) is ploughed down, the green material is first shredded with disc implements and, prior to sowing the winter crops, the field is packed.

Perennial (Sundial) Lupine. By virtue of its cold hardiness, sundial lupine (*Lupinus polyphyllus*) reaches maturity even in the North. During the first year, sundial lupine does not flower, forming instead a radical rosette with 10 to 15 blades or lone-stalked palmately compound leaves. It starts flowering and bearing fruit in the second year. If grown without fertilizing, sundial lupine produces the maximum amount of green material in the third or fourth year.

When intended for annual use, sundial lupine is sown under oat or barley and ploughed down in the second year in fallow, at full flowering stage or when grown pods appear on the lower parts of clusters.

If the lupine fallow is intended for growing spring crops, the plant material of the first cutting is used to fertilize fields in the neighbourhood. The aftermath appearing after mowing is ploughed down in the same field in autumn.

Ploughdown of sundial lupine creates favourable conditions for the development of winter and subsequent crops.

In the experiments carried out by the agricultural chemistry department of the Timiryazev Agricultural Academy in Moscow on the moderately loamy soddy podsolic soil of the educational farm "Dubki" (Moscow Region) with sundial lupine grown on fallow, the following yields (cent/ha) of winter rye (direct effect of green manure) and pea-oat mixture (aftereffect) were obtained:

	Rye (grain)	Pea-oat mixture
Without fertilizer	20.5	28.1
35 tons of manure per hectare	38.1	37.3
35 tons of sundial lupine per hectare	38.8	35.1

Sundial lupine is grown not only in crop rotation fields, but also in outside fields, on gully slopes, on waste land, and between rows of trees in orchards and forest nurseries. On such plots, sundial lupine is sometimes allowed to grow for six to eight years, its green material being used to fertilize neighbouring fields (first cutting for winter crops and second, for spring crops) or to be incorporated into pans around trees.

Annual fodder lupine is grown to obtain cheap high-protein fodder and to enhance the fertility of soils. Yellow fodder lupine is characterized by high yielding capacity, excellent nutritional value, while its stubble and root residues have a high fertilizing value.

In the Non-Black Earth zone, it is most promising to grow and use fodder lupine on cropped fallow, in which case the mown material is used as green fodder or ensilaged and the aftermath is used as fertilizer to treat winter crops. Fodder lupine should be mown preferably at the flowering stage. In Polesye and western parts of the Ukraine, mixed planting of fodder lupine with oat, maize, or winter crops to be used as green fodder is also promising. The best time to sow lupine under maize is early June when the main crop reaches a height of 20 to 25 cm and interrow tillage has been performed twice.

The best time to sow fodder lupine (to be grown independently) is five or six days after sowing early spring crops.

When fodder lupine is grown as both fodder and green manure, the plants are mown at the budding or flowering stage at a height of 8 to 10 cm. This ensures good growth of the aftermath. According to the Research Institute of Fodder, the aftermath does not grow well in the Moscow Region if lupine has been cut low. If intended for use as fodder and for ensilage, lupine is mown during the period from the flowering stage to pod formation.

Seradella *(Ornithopus sativus Broth)*. Seradella is an annual legume. It is grown independently in fields occupied by spring crops and on fallow. Depending on local conditions, used as green manure is all of its plant material (complete green manure), green material, or the growing aftermath. Of particular interest is integrated use of seradella, whereby

its green material serves as fodder, while the aftermath is used as fertilizer.

Seradella is a moisture-loving plant and prefers light soils with a weakly acidic reaction (salt extract pH 5-5.5). Heavy clayey, highly acidic, and alkaline soils are less suitable for this crop. Within the first four to six weeks, seradella roots grow intensively at the expense of the aboveground parts. On sandy and sandy loam soils, it responds well to application of potassium fertilizers, especially when they contain magnesium. Seradella actively takes up the phosphorus of ground phosphate rock.

On soils with a higher moisture content, seradella is grown as a subordinate crop. It is sown early in spring under winter crops or under seeded spring crops. If the soil does not contain enough moisture, seradella cannot be grown as a subordinate crop. After the nurse crop has been harvested, seradella develops till late autumn and can be used as fodder (green material) and as green manure (all plant material or only the aftermath).

Sweetclover. This crop thrives on neutral soils rich in calcium. On limed soddy podsolic soils, it produces higher yields of green material and seeds than annual and sundial lupine.

There are different sweetclover varieties and species: annual and biannual, white (*Melilotus albus*) and yellow (*Melilotus officianalis*). White sweetclover is more productive, while the yellow one matures earlier. Roots of sweetclover are more developed than those of all other green manure legumes. Therefore, it is characterized by high drought resistance and excellent fertilizing value even though its green material is less bulky. Sweetclover is used both as green fodder and as green manure, although its high coumarin content reduces its nutritive value somewhat. However, there are coumarin-free varieties.

Biennial sweetclover produces better green manure. It has a great variety of uses, including:

independent fallow crop sown under winter crops;

source of green material cut at the early flowering stage with the aftermath being ploughed down as fertilizer;

source of green material (first cutting) for use as fertilizer with the aftermath or green material of the second cutting being used as fodder;

source of green material for use as fodder (first cutting) and as fertilizer (second cutting).

In contrast with annual fodder lupine and seradella, sweet-clover blossoms earlier, which permits this crop to be mown and its aftermath to be ploughed down as green manure at earlier stages.

The first cutting of its green material is performed before or, in an extreme case, early at the flowering stage. When cut later, sweetclover stalks soon become too rough, whereby their nutritive and fertilizing value is reduced (the green material decomposes in the soil very slowly when it fixes large amounts of mineral nitrogen). The aftermath to be used as green manure is ploughed down in autumn or early spring.

5.4 Factors of Green Manure Effectiveness

The effectiveness of green manure depends on the yield of the crops serving as its source. The higher the yield and the greater the quantity of the incorporated green manure, the stronger its effect and aftereffect.

The green manuring schedule depends on a number of factors. If the soil does not contain enough mobile nitrogen for the initial nutrition of the crop under treatment, green manure is incorporated earlier (to allow enough time for its decomposition). When the danger of soil desiccation is imminent, incorporation of green manure should not be delayed. When it is ploughed down too late, the soil often subsides after sprouting of winter crops, which exposes their tillering nodes and reduces their winter hardiness.

The decomposition rate of incorporated green manure depends on the ploughdown depth, age of the green manure crop, soil texture and moisture content. The deeper the ploughdown, the older the plants (the rougher their stalks), and the heavier the soil texture, the slower the decomposition rate of the green manure and vice versa. In order to slow down the decomposition of green manure in the soil, it has to be ploughed down later (towards seeding of the crop to be treated) and deeper, whereas for faster decomposition green manure has to be incorporated to a shallower depth and earlier. Using mixtures of legumes and cereals as green

manure or incorporation of more inert, slowly decomposing materials (peat, straw, reed, etc.) together with green manure slows down the decomposition of the latter in the soil; addition of small amounts of horse manure or fecal matter to green manure (for enrichment with microorganisms) accelerates the decomposition.

When leguminous (fodder, grain, or green manure) crops are grown, it is usually sufficient to incorporate phosphorus-potassium fertilizers into the soil. The requirements of legumes for nitrogen nutrition must be met primarily by the activity of nodule bacteria. One of the predominant ways to enhance nitrogen fixation by legumes is application of the bacterial preparation nitragin containing active strains of nodule bacteria. These bacteria are specific: some species or strains are capable of forming nodules on clover roots but not on those of pea, alfalfa, lupine, and other legumes. Groups of bacteria that form nodules on the roots of lupine and seradella do not do so on clover and pea roots, and so forth.

Nodule bacteria strains also differ in virulence and activity. Virulence is the ability of nodule bacteria to penetrate legume roots via root hairs and to form nodules. If the virulence of nodule bacteria in nitragin exceeds that of the less active bacteria present in the soil, they penetrate roots faster and in greater numbers. By activity in this context is meant the capacity of nodule bacteria to fix atmospheric nitrogen. Only active strains of these bacteria supply plants with nitrogen, whereas the inactive ones inhibit the host plant. In other words, the nodule bacteria used in the preparation of nitragin must be highly virulent and active.

Old cultivated soils on which legumes are often grown contain sufficient amounts of active nodule bacteria, and the roots of leguminous plants develop many nodules even without being treated with nitragin. However, when legumes are grown where they have never been sown before, no nodules form on their roots (without nitragin treatment). In acid soils, nodule bacteria soon lose their activity. In boggy soils, they cannot be found at all. Hence, nitragin should be applied to such soils each time legumes are sown anew. Liming of acid soils, application of organic, phosphorus-potassium, and micronutrient fertilizers (boron, molyb-

denum), as well as increasing the moisture content to the optimal level enhance the activity and virulence of nodule bacteria, while application of nitrogen fertilizers produces an opposite effect.

A bottle (500 g) of commercially produced nitragin is sufficient to treat about a hectare of a field occupied by legumes. Nitragin can be kept in storage for nine months since the date of its production. If stored longer, the activity of its nodule bacteria is greatly reduced. Nitragin must be stored in a dry and cool room at temperatures ranging from 0 to 10 °C. Storage in a humid room leads to formation of mold which contains many antagonists of nodule bacteria. Alternating freezing and thawing of the preparation also reduces the population of active bacteria.

Nitragin should not be kept in the same room with volatile toxic chemicals because their vapours kill the bacteria.

Nitragin is placed in the soil together with leguminous seeds. To this end, the necessary quantity of the preparation is put into a clean vessel (bucket) which is filled with pure water at a rate of two cups per 10 kg of small seeds (clover, alfalfa, sweetclover, seradella) or a cup per 20 kg of larger seeds (pea, lupine, fodder beans, kidney bean, soybean, etc.). Then, nitragin is mixed with water for three to five minutes using a wooden paddle and, without letting the mix settle down, seeds spread in a uniform layer over a clean wooden floor or canvas are wetted evenly. The seeds are shoveled up until they become all uniformly wetted. As soon as the seeds become dry, they are packed in sacks or bags and carried to the field. Only those seeds that are going to be sown within 24 hours must be treated at once.

A molybdenum fertilizer may be dissolved in the same volume of water used for mixing with nitragin, at a rate of 25 to 50 g Mo per hectare dosage of seeds.

When seeds must be treated with nitragin and disinfected with formalin, they first undergo the disinfection, are properly aerated and dried, and only then treated with nitragin. Seeds treated with granosan are conditioned with nitragin (just as any other bacterial preparation) only on the day of sowing.

Chapter 6

Fertilizer System

6.1 Tasks to Be Accomplished by the Fertilizer System

A rational fertilizer system complying with the natural, managerial, and economic aspects of farming is a predominant factor of high crop yields and quality as well as soil fertility regardless of whether the latter is enhanced or simply kept at its former level. In the course of its evolution, the fertilizer system can be divided into two stages:

(1) drafting a recommendation for fertilizer application, substantiated by a feasibility study;

(2) putting the recommendation into practice at a particular state or collective farm.

At the first stage, the fertilizer system in crop rotation may be referred to as an organic and inorganic fertilizer application program specifying the types of fertilizers, their rates, application schedule and techniques with due regard for individual crops as well as soil, climatic, and other conditions. Such a program must be prepared by a specialist, usually the fertilizer agronomist of the farm. To do this, he must have access to the statistics showing the dynamics of crop yields over the preceding three to five years, plus estimates of future yields, crop rotations (or at least the availability of fields for a realistically feasible alternation of crops), agrochemical charts, a soil map, and organic fertilizer accumulation schedules. The program is often written for a farm by a research institution.

Of particular importance is implementation of the fertilizer application program at the farm. At this stage, a complex of organizational and agrotechnical activities must be undertaken. The fertilizer system cannot be taken out of the overall farm management context.

Thus, the fertilizer system in crop rotation at a farm is essentially a blend of management, agrochemical, and agrotechnical activities aimed at implementing a scientifically substantiated program of fertilizer application, specifying

types of fertilizers, their rates, application time and techniques with respect to individual crops. The factors determining this program include the biological characteristics of crops, expected yields, soil and climatic conditions, aftereffect of the fertilizers, specific features of each field, nutrient balance in the crop rotation, and the effect of fertilizers on the crop quality and enhancement (or maintenance) of soil fertility. A prerequisite of the fertilizer system is its economic efficiency. The system calls for application of fertilizers to every field according to plan over a long period of time.

The fertilizer system is to accomplish the following main tasks:

(1) Increasing crop yields and quality.

(2) Improving and gradually equalizing the fertility of all fields or, in some cases, maintaining their fertility at its former level.

(3) Effective application of fertilizers with due account for intensification of cropping and environmental control.

Depending on the specialization of farms and the distance of crop rotation fields from livestock farms or complexes, three types of fertilizer system can be distinguished: (1) manure-inorganic, or combined; (2) inorganic, or manure-free, based on application of only inorganic fertilizers; and (3) manure system, typical primarily of farms specializing in commercial livestock husbandry and based on application of manure without litter, supplied by barnyards.

6.2 Physiological Factors Determining the Fertilizer Requirements of Farm Crops

Uptake of Nutrients at Different Growth Stages. The nutrient uptake by plants changes perceptibly with their age. The process of plant nutrition comprises two distinct periods of uptake of a particular nutrient, i.e. critical and maximal. The former implies that period in plant development when deficiency of a nutrient adversely affects plant growth to the extent that subsequent adequate supply of this nutrient cannot fully remedy the situation.

Experiments have shown that the critical period for farm crops, in terms of phosphorus and nitrogen, covers the first

10 to 15 days after sprouting. An acute deficiency in potassium at the initial stages of plant development also reduces yields considerably. However, application of potassium fertilizers at a later point in time can substantially improve yields, whereas lack of phosphorus or nitrogen at this stage cannot be compensated later.

In the field, the critical period in inorganic nutrition usually coincides with low activity of microorganisms mineralizing the organic matter of the soil. This becomes manifest in early spring when low temperature inhibits the microbiological activity of the soil.

The maximal period in plant nutrition is when the daily average uptake of a particular nutrient reaches its maximum. This period corresponds to later stages of plant development. In most cases, it coincides with maximum accumulation of the dry biomass, although there is no direct relationship between the two in the strict sense. Notably, in young plants, the uptake of nutrients is always far ahead of dry matter accumulation. This is why young plants contain more nitrogen, phosphorus, potassium, and other nutrients per unit dry weight than older ones.

The nutrition period of some plants is much shorter than the vegetation period (hemp, flax, and most cereals). For others, it is prolonged and almost coincides with the vegetation period (sugar beet, potatoes, cabbage, etc.). Depending on the biological characteristics of plants, their nutrition can be regulated according to growth stages, which permits attaining the desired crop yields and quality. The periodicity of plant nutrition has made it possible to define the theoretical principles of split fertilizer application (to different soil layers at different points in time). Application of fertilizers at once to a single soil layer does not always allow their full potential to be realized. Therefore, an adequate system of plant nutrition in the field calls for combination of the basal fertilizer (to a depth of 15 to 25 cm) with those applied at seeding (to a depth of 3 to 10 cm) and sometimes those used for soil and foliar dressing.

Yield Removal of Nutrients. Various plants take up nutrients from the same soil not only in different amounts but also at different ratios between them. Apart from the specific and varietal characteristics of crops, soil and cli-

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matic conditions play a major role in nutrient uptake. The nutrient requirements of various crops are expressed not only in terms of yield removal of nutrients, but also per unit yield of the main product with due account for the by-products (straw, tops). Accumulation of inorganic nutrients in a plant reaches its maximum early during its maturation. This corresponds to the notion "nutrient requirements of plants". At late stages of development, nutrient losses occur due to defoliation and an efflux of assimilates from roots into the soil. Distinction must be made between biological and commercial removal of nutrients.

Biological removal implies the amount of nutrients consumed by plants to build the biomass of a particular crop (grain + straw + afterharvesting and root residues, including the nutrients partially returning into the soil). It comprises commercial and residual removal.

Commercial removal represents the portion of nutrients that is contained in the useful products carried from the field after harvesting (e.g. grain and straw, roots and tops). If the useless part of the crop (straw and tops) is left in the field, the nutrients in it are subtracted from the commercial removal.

The residual part of biological removal includes the nutrients remaining in the field in the form of aftermath and root residues, fallen leaves, lost grain, and a certain amount of nutrients transferred from roots into the soil. Experiments have shown that the residual removal may involve a major portion of the nutrients that have contributed to the yield (Table 6.1).

Hence, application of fertilizers based on the amount of commercial removal of nutrients does not comply with their actual amounts required by crops. Plants require nutrients not only for the useful (commercial) portion of the yield, but also for formation of the roots, stalks, and leaves, which remain in the field. Since the residual portion of the removal remains in the field and exerts an aftereffect on other crops as a result of mineralization, the nutrient requirements of crops are most often expressed, for practical purposes, in terms of commercial removal per 10 centners of the main product with due account for the corresponding amount of by-products.

Table 6.1. Approximate Contents of N, P_2O_5, and K_2O in the Useful Part of Some Crop Yields (% of biological removal) (according to different sources)

Crop	N	P_2O_5	K_2O
Perennial grasses (clover with timo- thy)	48	48	52
First-year clover	40	40	50
Second-year clover	40	40	47
Annual grasses (vetch, pea with oat)	61	68	66
Cereals	75	79	64
Potato	71	72	79
Maize for silage	80	82	71
Fodder beans for silage	76	85	70
Tomato	66	72	86
Cucumber	53	60	58
Cabbage	55	49	38
Bulb onion	67	73	80
Cauliflower	25	21	27

In practice, fertilizer rates for farm crops are usually determined from nutrient removal per 10 centners of the main product (Table 6.2).

Crops take up nutrients at the following N : P_2O_5 : K_2O ratios: cereals—2.5-3.0 : 1 : 2.2-3.0; ensilage crops—2.1-2.7 : 1 : 3.3-3.8; vegetables—2.0-2.9 : 1 : 3.0-3.6; potato, fodder root crops, and sugar beet—3.0-3.3 : 1 : 4.2-4.7. Hence, ensilage and vegetable crops take up more potassium than cereals but less nitrogen and especially potassium than potatoes, fodder root crops, and sugar beet. The removal of nutrients per unit main product (taking into account by-products) is not a constant quantity. It may vary widely (by a factor of 1.5 and more) depending on soil and climatic conditions, crop varieties, yield, fertilizer rates, and irrigation. As a rule, nutrient removal per unit main product increases when fertilizers are used. This is especially true in the case of potassium, followed by nitrogen and, to the least degree, phosphorus. If the percentage of by-products in the yield increases, the nutrient removal per 10 centners of the main product (taking into account by-products) increases, too. If a crop is adequately supplied with nutrients but is ad-

Table 6.2. Approximate Removal of N, P_2O_5, and K_2O Per Unit Yield of Some Crops (according to different sources)

Crop	Main product	Removal (kg) per 10 centners of main product plus by-products			$N : P_2O_5 : K_2O$ ratio
		N	P_2O_5	K_2O	
Winter wheat	Grain	35	12	25	3.0 : 1 : 2.2
Winter rye	Ditto	30	12	28	2.5 : 1 : 2.3
Spring wheat	Ditto	38	12	25	3.2 : 1 : 2.1
Barley	Ditto	27	11	24	2.5 : 1 : 2.2
Maize	Ditto	34	12	37	2.8 : 1 : 3.0
Oat	Ditto	30	13	29	2.3 : 1 : 2.3
Millet	Ditto	33	10	34	3.3 : 1 : 3.4
Buckwheat	Ditto	30	15	40	2.0 : 1 : 2.7
Pea	Seeds	30*	15	20	2.0 : 1 : 1.3
Vetch	Ditto	30*	14	16	2.1 : 1 : 1.1
Sunflower	Ditto	60	26	180	2.3 : 1 : 7.0
Fibre flax	Fibre	80	40	70	2.0 : 1 : 1.8
	Straw	15	7	12	2.1 : 1 : 1.7
Hemp	Fibre	200	60	100	3.3 : 1 : 1.7
Cotton	Raw fibre	45	15	50	3.0 : 1 : 3.3
Early potato	Tubers	5.0	1.5	7.0	3.3 : 1 : 4.7
Late potato	Ditto	6.0	2.0	9.0	3.0 : 1 : 4.5
Sugar beet	Roots	5.9	1.8	7.5	3.3 : 1 : 4.2
Fodder beet	Ditto	4.9	1.5	6.7	3.3 : 1 : 4.5
Pea with oat	Forage	3.5*	1.4	5.0	2.7 : 1 : 3.8
Vetch with oat	Ditto	3.5*	1.2	4.5	2.9 : 1 : 3.8
Maize	Ditto	3.0	1.2	4.5	2.5 : 1 : 3.8
Winter rye	Ditto	3.0	1.2	4.5	2.5 : 1 : 3.8
Clover with timothy	Hay	14*	6	20	2.3 : 1 : 3.3
Timothy	Ditto	16	7	24	2.3 : 1 : 3.4
Vetch with oat	Ditto	15*	6	20	2.5 : 1 : 3.3
Cabbage	Heads	3.4	1.3	4.4	2.6 : 1 : 3.4
Table carrot	Roots	3.2	1.2	5.0	2.7 : 1 : 4.2
Table beet	Ditto	2.7	1.5	4.3	1.8 : 1 : 2.9
Tomato	Fruits	3.2	1.1	4.0	2.9 : 1 : 3.6
Cucumber	Ditto	2.8	1.4	4.4	2.0 : 1 : 3.1
Bulb onion	Bulbs	3.7	1.3	4.0	2.8 : 1 : 3.1
Fruits and berries	Fruits and berries	5.0	3.0	6.0	1.7 : 1 : 2.0
Grape	Berries	1.7	1.4	5.0	1.2 : 1 : 3.6
Tea	Dry leaves	50	7	23	7.2 : 1 : 3.3

* Nitrogen used from the soil and fertilizers without fixation.

versely influenced by an environmental factor or a combination of several factors, the removal of nutrients per unit main product increases in this case. And vice versa, a favourable combination of various factors is conducive to a more economical utilization of nutrients to attain the yield.

Uptake of Nutrients from the Soil. The factor of utilization of a particular nutrient taken up by crops from the soil represents its expenditure versus total content of the mobile form of this nutrient in a hectare of the arable layer and is expressed in per cent (or as a decimal fraction):

$$K = \frac{a}{b} \cdot 100$$

where a is the amount of nutrient removed by the crop from a hectare of unfertilized soil (in kg) and b is the content of the mobile form of the nutrient in a hectare of the arable layer (in kg).

The nutrient content (in kg) in the arable layer (usually 0-20 cm) per hectare is determined by multiplying its content according to the chart (in mg per 100 g of soil) by a factor of 30. For example, 10 mg P_2O_5 per 100 g of soil $\times$ 30 = = 300 kg P_2O_5 per hectare.

The factors of utilization of the mobile forms of nutrients may vary widely not only by virtue of the biological characteristics of different crops, but also as a result of changes in the environmental factors (soil fertility and acidity, weather conditions, level of agrotechnics, etc.). This makes it difficult to use them in calculations of fertilizer rates. The higher the content of a nutrient in its available form in the soil, the lower the factor of its utilization by plants. Application of organic and inorganic fertilizers as well as liming enhance the mobilization of soil nutrients, and the factors of their utilization by plants are improved. A positive effect is produced by irrigation. In this case, the soil nutrient utilization factors may increase 1.5- to 2-fold. Cultivation of the soil and the level of farming practices also affect these factors. For example, in clean fallow, the annual humus mineralization rate is three to five times higher than in soils occupied by crops. As a result, clean fallow may accumulate up to 80-120 kg of inorganic nitrogen per hectare plus other

nutrients, which provides for higher yields and soil-derived nutrient utilization factors.

The arbitrary nature of the utilization factors is also due to the fact that only the nutrient content in the arable layer of the soil is taken into account. In fact, plants also take up nutrients from deeper layers.

Each commonly used method of agrochemical analysis of a particular soil type to determine mobile forms of phosphorus and potassium must be based on its own soil-derived nutrient utilization factors (Table 6.3).

Table 6.3. Average Factors of Utilization of P_2O_5 and K_2O by Various Farm Crops from Different Soils (%)

Crop	Soils					
	soddy podso-lic	grey forest	non-cal-careous cherno-zems	calcareous cherno-zems	chest-nut	siero-zems
	Kirsanov's method		Chirikov's method	Machigin's method		
P_2O_5						
Cereals, annual and perennial grasses	5	8	10	15	15	15
Maize for silage	5	8	10	15	15	—
Fibre flax	3	—	—	—	—	—
Potato	7	10	10	—	—	—
Grain maize	—	10	10	30	30	—
Sugar beet	—	10	10	—	—	—
Sunflower	—	—	15	30	30	—
Cotton	—	—	—	—	20	20
K_2O						
Cereals, annual and perennial grasses	10	12	12	5	5	5
Maize for silage	20	25	20	7	7	—
Fibre flax	5	—	—	—	—	—
Potato	20	25	25	—	—	—
Grain maize	—	30	25	10	10	—
Sugar beet	—	40	30	—	—	—
Sunflower	—	—	40	20	15	—
Cotton	—	—	—	—	10	10

The utilization factors of Table 6.3 have been determined on soddy podsolic and grey forest soils at average mobile P_2O_5 and K_2O contents in the soil, on non-calcareous chernozems at average P_2O_5 and higher K_2O contents, on calcareous chernozems, chestnut soils, and sierozems at average P_2O_5 and high K_2O contents.

The utilization factor of the easily hydrolyzable nitrogen on soddy podsolic, grey forest, chestnut, and sierozemic soils is taken equal to approximately 20 per cent, while on chernozems it is taken equal to 20-30 per cent.

Uptake of Nutrients from Organic and Inorganic Fertilizers. The factor of nutrient utilization from fertilizers is indicative of the percentage nutrient uptake by crops with respect to the total amount of the nutrient incorporated with fertilizer, responsible for yield increase. The utilization factor is most often determined by the difference method based on the ratio between the difference in yield removal of the nutrient on fertilized and control plots and the amount of the nutrient incorporated into the soil together with the fertilizer and is expressed as percentage (or as a decimal fraction):

$$K = \frac{R_y - R_0}{C} \cdot 100$$

where R_y is the yield removal of the nutrient (in kg/ha) on the fertilized plot, R_0 is the yield removal of the nutrient (in kg//ha) on the control plot, and C is the amount of the nutrient (in kg/ha) incorporated with the fertilizer.

It is more correct to determine the utilization factor of a nutrient from a particular fertilizer against the background of other nutrients incorporated with the fertilizer, as opposed to comparison with an experiment without fertilizer application (absolute control).

The difference method of calculation suffers from a serious drawback. It is based on an arbitrary assumption that fertilizer application does not affect the amount of soil-derived nutrients taken up by crops. In reality, this is not so.

The utilization factors of nutrients from fertilizers are usually more stable than those of soil-derived nutrients. However, they may also vary widely depending on soil properties, weather conditions, biological characteristics of the

crops, fertilizer rates and forms, techniques of their appli-
cation, and other factors. For example, the utilization fac-
tor of a nutrient from fertilizer decreases with increasing
rate of the applied fertilizer, content of this nutrient in the
soil, and soil acidity in the case of broadcasting as opposed
to local placement.

For practical purposes, Table 6.4 gives annual average
utilization factors of nutrients from fertilizers and those
over a crop rotation cycle under normal cropping conditions.

Table 6.4. Average Utilization Factors of Nutrients from Fertilizers (%)

Year	From organic fertilizers			From inorganic fertil- izers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1st	20-25	25-30	50-60	50-60	15-20	50-60
2nd	20	10-15	10-15	5	10-15	20
3rd	10	5	—	5	5	—
Over a crop rota- tion cycle	50-55	40-50	60-75	60-70	30-40	70-80

According to Smirnov, utilization of nitrogen in the first
year of the aftereffect averages two to three per cent and, in
the second year, one to one and a half per cent of the applied
amount. Nonetheless, owing to the uptake due to aftereffect
over the crop rotation cycle, the overall factor of additional
utilization of fertilizer nitrogen by crops amounts to 8 to
10 per cent, as compared to the first year. Therefore, in
calculations of fertilizer rates, the utilization factor of
inorganic fertilizer nitrogen within the first year is assumed
equal to 60-70 per cent without taking the aftereffect into
account.

**Effect of Afterharvesting and Root Residues of Farm
Crops on the Nutrient Regime of the Soil.** It was shown above
(Table 6.1) how much nutrients removed biologically remain
in the residual portion of a yield (in afterharvesting and root
residues). The strongest aftereffect on the nutrition of sub-
sequent crops is exerted by the root and afterharvesting
residues of leguminous crops (Table 6.5). This is why they
must be taken into account in the first place when program-

Table 6.5. Approximate Quantities of Afterharvesting and Root Residues of Various Crops and Their Nutrient Contents

Crop	Main prod- uct yield (cent/ha)	Dry afterhar- vesting and root resi- dues in the topsoil (cent/ha)	Nutrient content in root and af- terharvesting residues (kg/ha)			C : N ratio
			N	P_2O_5	K_2O	
1st year clover (hay)	20	36	78	22	37	12
	58	74	158	44	64	
2nd year clover (hay)	36	50	106	30	47	12
	57	91	194	55	78	
Seed pea	25	22	40	8	24	12
Winter wheat	22	25	27	5	14	25
	40	32	28	7	18	
Barley	20	25	22	6	14	25
Maize for silage	—	46	29	12	72	40
Potato	—	13	11	3	32	23
Hemp	—	20	12	4	13	44
Cabbage	—	13	17	5	6	—
Tomato	—	10	16	5	6	—
Cucumber	—	8	11	3	4	—
Carrot	—	8	9	3	5	—
Onion	—	5	6	2	2	—

ming the fertilizer system in crop rotation. As opposed to other crops, legumes have the narrowest carbon-to-nitrogen ratio, close to that observed in good manure, in their afterharvesting and root residues. Therefore, the mineralization of such residues of leguminous grasses and pulses is intensive; the utilization factors of nutrients from the afterharvesting and root residues of the preceding leguminous crop are almost the same as those of organic fertilizer nutrients. First of all, the aftereffect of their nitrogen must be taken into consideration. For instance, the factor of nitrogen utilization from the afterharvesting and root residues of legumes by the first, second, and third crops may be taken equal to 25, 15, and 10 per cent, respectively. It is common to assume that perennial leguminous and leguminous-cereal grasses leave 10 to 15 kg N per ton of hay in the form of root and afterharvesting residues. Hence, if the hay yield over two years amounts to 80 centners per hectare, a hectare of the soil will retain about 120 kg of nitrogen. The first subse-

quent crop (e.g. a cereal) utilizes 25 per cent or 30 kg of nitrogen, which makes it possible to increase the grain yield by approximately 10 centners per hectare. This amount of nitrogen is equivalent to 50 kg of inorganic fertilizer nitrogen ($\frac{30}{60} \cdot 100 = 50$ kg, where 60 is the inorganic fertilizer nitrogen utilization factor within the first year). The afterharvesting and root residues of leguminous crops (annual grasses) contain about half the nitrogen removed by the valuable part of the yield.

6.3 Impact of Various Factors on the Effectiveness of Organic and Inorganic Fertilizers

Soil and Climatic Conditions. Complete inorganic fertilizers (NPK) are most effective in the soddy podsolic soil zone. Their effectiveness in the European part of the USSR diminishes from north-west towards south-east (from the meadow-forest towards steppe and arid steppe zones), and in the Asian part from east westwards. This pattern can be explained by differences in soil fertility and availability of moisture. The effect of nitrogen fertilizers is particularly manifest on the soddy podsolic and grey forest soils of the meadow-forest and forest-steppe zones as well as on the podsolized, leached chernozems of the northern and western parts of the forest-steppe and on all soils of irrigation farming areas. In the south and east of the steppe zone in the European part of the Soviet Union, nitrogen fertilizers are less effective and stable on leached and deep chernozems because of their low moisture content. Nitrogen fertilizers are also less effective on soils deficient in phosphorus and potassium.

Phosphorus fertilizers are most effective on typical, ordinary, and southern chernozems, chestnut soils, and sierozems, that is, in the forest-steppe, steppe, arid steppe, semi-desert, and desert zones where the content of mobile phosphorus in the soil is low (Table 6.6). Since the soils of the meadow-forest zone are acutely deficient in phosphorus, the effectiveness of phosphorus fertilizers with adequate nitrogen supply is also high there.

The effect of potassium fertilizers is most pronounced on soils with light texture such as (sandy and sandy loam)

soddy podsolic soils as well as peat-boggy and river plain
soils. As a rule, there is enough potassium in moderately
loamy, heavily loamy, and clayey soils. |Potassium fertil-
izers are least effective on chernozems, chestnut soils, brown
soils, and sierozems adequately supplied with mobile potas-
sium (Table 6.6).

Table 6.6. Arable Area Distribution in Terms of Mobile Phosphorus and
Potassium Contents According to Soil Zones in the USSR
($\%$ of the surveyed area) (according to Derzhavin, 1976)

Zone (soils)	Mobile phosphorus/potassium content			
	very low and low	mod-erate	in-creased	high and very high
Meadow-forest (soddy podsolic)	67/52	20/28	6/11	7/9
Forest-steppe (grey forest, podso-lized, leached, and typical chernozems)	41/15	38/27	13/20	8/38
Steppe (ordinary and southern chernozems)	51/4	36/19	9/22	4/55
Arid steppe (dark chestnut and chestnut)	53/4	35/13	7/19	5/65
Semidesert (light chestnut and brown)	44/3	37/9	11/18	8/70
Desert and piedmont desert-steppe (grey-brown, sierozems, takyr, solonchaks)	85/25	12/22	—/14	3/39
Moist subtropics (yellow and red)	7/51	15/29	—/—	78/20

In the case of advanced farming practices, inorganic fer-
tilizers ensure high yield increases.

Organic fertilizers are highly effective in areas with soddy
podsolic soils, grey forest soils, and podsolized chernozems.
Their effectiveness decreases from northwest towards south-
east in the European part of the USSR and from east west-
wards in the Asian part. The residual effect of organic fertil-
izers in the southern regions is more pronounced than in the
northern ones. In northern, north-western, cold and high-
rainfall regions as well as on inadequately cultivated soils,
higher organic fertilizer rates are recommended, as com-
pared to the south and arid south-east, chernozems and highly
cultivated soils.

To apply fertilizers one must take into consideration the weather conditions of the current and preceding years. For example, insufficient rainfall in autumn reduces the effectiveness of nitrogen fertilizers in the following year and makes phosphorus ones more important. In the year following a rainy autumn, nitrogen fertilizers become more effective. Under conditions of excess moisture, crops need more potassium, while in the case of short spells of cold weather in spring they need more phosphorus. Fertilizers reduce the water requirements accounting for unit yield by 10 to 20 per cent and mitigate the deleterious effect of drought (especially organic fertilizers). In turn, irrigation or availability of moisture is conducive to a more effective application of fertilizers.

In arid regions, only a single row fertilizer is applied in most cases, primarily a phosphorus one.

Low temperatures early in plant growth produce the worst effect on nitrogen and phosphorus nutrition. An excessively high temperature also slows down the uptake of nutrients by plants.

Another factor affecting the effectiveness of fertilizers is the microbiological activity of the soil.

Systematic application of fertilizers causes rapid changes in soil acidity, total exchangeable bases, the degree of base saturation, and the content of mobile potassium and phosphorus and extremely slow changes in the humus content and exchange capacity, the latter two varying depending primarily on organic fertilizers.

Agrotechnical Conditions. Timely and proper cultivation of the soil, sowing or planting of crops at the right time from the agrotechnical standpoint, selection of a good precursor, appropriate crop rotation, weed, pest and crop disease control—all these factors produce a pronounced positive impact on the effectiveness of fertilizers. Timely and proper cultivation of the soil improves its water, air, and microbiological regimes, promotes plant growth, and intensifies the uptake of soil-derived and fertilizer nutrients via roots. The effect of precursors resides in that they leave in the soil various amounts of afterharvesting and root residues, are fertilized in different ways, take up water and nutrients dissimilarly, differently affecting the moisture content and nutrient

regime of the soil, its microbiological activity, weediness, and proliferation of pests and diseases. Certain crops (lupine, mustard, sainfoin, sweetclover), easily taking up almost unavailable soil nutrients, convert them into an available form for other crops as a result of mineralization of the afterharvesting and root residues or ploughed down green manure. Vegetables and also the row crops of field rotations actively take up potassium. As opposed to late crops characterized by a longer vegetation period, early ones usually take up less nutrients and free the field earlier with the result that better conditions are created for mobilization of soil-derived nutrients and plant nutrition. Legumes grown on cultivated soils not only supply themselves with nitrogen, but also enrich the soil with it. Therefore, the crops following legumes are treated with nitrogen fertilizers at lower rates or not at all. On the other hand, legumes take up phosphorus and potassium from the soil in great amounts so that the subsequent crop may suffer from deficiency in these nutrients. Timely ploughing of the soil occupied by perennial leguminous grasses creates more favourable conditions for decomposition of the sod and the associated accumulation in the soil of mobile nutrients, particularly nitrogen.

The cultivation technique and fertilizer incorporation depth also play an important role in plant nutrition. Incorporation of fertilizers into a moist soil layer that never dries up is conducive to better nutrition conditions and enhances the effectiveness of the incorporated fertilizers, in contrast with shallow or surface placement. Moreover, soil cultivation is essentially a weed control procedure, which also improves the nutrition conditions for cultivated crops. Cultivation deepens the arable layer with the result that plants develop an extended root system and extract additional nutrients from deeper soil layers.

The role of individual nutrients depends on the biological characteristics of a given crop variety. More productive crops require higher fertilizer rates. Notably, modern high-yielding varieties of grain crops are more demanding insofar as nitrogen and phosphorus nutrition is concerned.

The amount of applied fertilizers must comply with the sowing rates and times. As a rule of thumb, adequately fertilized soils should be sown to a lesser extent owing to

the more pronounced tillering or development of the crops under favourable conditions. Less tillered, squat, and lodging-resistant varieties respond better to increased fertilizer rates at the same sowing rate.

In irrigation farming, it is important to stick to the watering schedule. Irrigation increases the effectiveness of fertilizers by a factor of 1.5 to 2 with nitrogen fertilizers becoming predominant.

Crop rotation, whereby certain crops are alternated in a definite pattern, is another factor influencing the effectiveness of fertilizers. Generally, it is much higher in crop rotation, as compared to a one-crop system, by virtue of more complete utilization of soil-derived and fertilizer nutrients by the various crops and due to the phytosanitary role of crop rotation.

The effectiveness of inorganic and organic fertilizers is also substantially enhanced by liming of acid soils and gypsuming of alkaline ones.

6.4 Joint Application of Organic and Inorganic Fertilizers

Pryanishnikov wrote: "The highest yields are attained by combining manure with chemical fertilizers, this combination permitting crops to be adequately supplied with available nutrients at the early stages of their development, while manure serves as a reserve of nutrients that gradually become available."

Combination of manure with fertilizers is more often than not more effective than equivalent amounts of manure nutrients alone or those of separately applied inorganic fertilizers. This additional effect is due primarily to the increased microbiological activity of the soil (as a result of its enrichment with microorganisms introduced with manure and supply of nutrients easily available to the microorganisms in the form of inorganic fertilizers), hence, more intensive decomposition of the organic matter present in manure and in the soil. The degree of fixation of inorganic fertilizer phosphorus in the soil is reduced. A large quantity ′ of micronutrients also finds its way into the soil with

manure. Decomposition of manure liberates carbon dioxide which enriches the surface air layer, thereby increasing the productivity of photosynthesis in plants.

Joint application of manure and inorganic fertilizers is most advisable for crops intolerant to high soil solution concentrations but requiring a lot of nutrients throughout the vegetation period to produce a high yield (cucumbers, onions, maize).

It is appropriate at this juncture also to consider the effect of organic and inorganic fertilizers on one of the most important indicators of soil fertility—humus content. In practical farming, conserving humus in rich soils and increasing its content in poor ones must be among the tasks of paramount importance. The results of perennial experiments indicate that cropping without fertilizers over a long period of time leads to a drastic decrease in the humus content in the soil. For example, in soddy podsolic soils, it decreases over a period of 30 to 50 years by 25, 50 and even more per cent. On chernozems of the Ukrainian Steppe Reserve, the humus content in the 0-25 cm soil layer decreased from eight to five per cent, or by a factor of 1.6, over the past hundred years. An average of one per cent of humus is mineralized each year in the arable layer of soddy podsolic soils, and 0.4 to 0.5 per cent in chernozems. In clean fallows, the annual mineralization rate is three to five times higher. Long-term stationary experiments also show that, after application of manure or inorganic fertilizers alone at low rates, decomposition of the organic matter of the soil proceeds faster than its build-up, and the humus content eventually decreases. The process of humus formation largely depends on crop rotation patterns and rates of inorganic and, especially, organic fertilizers. Another finding in long-term experiments is that, in order to maintain the original humus content in soddy podsolic soils of medium and heavy texture, one must apply an average of 10 t/ha of high-quality organic fertilizers each year, 15 t/ha being the recommended application rate for light soils and 6 to 8 t/ha for chernozems.

Manure must first of all be supplemented with nitrogen fertilizers in view of the fact that crops extract from manure, within the first year, primarily phosphorus and potassium.

Manure should preferably be applied to row crops. Inter-

row cultivation intensifies the mineralization of organic matter, and the manure nutrient uptake by crops is more complete, especially by those with a long vegetation period.

Correct combination of manure with inorganic fertilizers in crop rotation contributes substantially to its productivity.

6.5 Fertilizer Application Schedules and Techniques

The terminology associated with fertilizer application must be clearly defined.

Distinction is usually made between three application procedures: basal (preseeding) application, row (drilling, starter) application, and dressing (postseeding or postplanting application).

Fertilizers may be applied in autumn, in spring, in summer, in certain months, and so on.

Application techniques include overall (broadcasting), localized (hill, spot, seedbed), localized band, reserve, mechanized, land, aerial, and others.

Incorporation techniques include ploughdown, placement by cultivator, disking in, and so on.

Different machines are used in basal application, starter application, and dressing.

Fertilizers must be incorporated in such a manner as to be readily available to crops throughout their vegetation period, be in the root development zone, promote root growth, and be fixed by the soil as little as possible. Fertilizers placed in the deeper, moist arable layer of the soil are better utilized by crops almost throughout the vegetation period. The lighter the soil, the deeper the fertilizers must be placed.

While incorporating fertilizers, one must take into account the possible migration of nutrients in the soil together with gravitational water and as a result of diffusion, as well as various losses. The process of nutrient migration by way of diffusion in the soil is insignificant, especially in the case of phosphorus. Of particular importance is the migration of nutrients together with downward and upward flows of water. This is especially true insofar as nitrogen fertilizers are concerned, when leaching of nitrates brings about nitrogen losses and pollution of the environment. In a humid

climate, pronounced leaching of nitrate nitrogen (up to 20 kg/ha and more) is observed only in light soils and fallow fields. Nitrogen losses due to leaching of nitrates from sown loamy soils are usually lower at moderate nitrogen fertilizer rates. Nitrates are leached mainly in early spring and late autumn, when the field is free of crops. In irrigated areas with hot climate, nitrates rise to the surface with the capillary flow of water (as a result of evaporation) and accumulate in the top desiccating soil layer. Therefore, it is important to time properly the application of nitrogen fertilizers with due account for the rate of nitrification of ammonia nitrogen. Accumulation of large amounts of nitrates in the soil may also lead to significant nitrogen losses due to denitrification, which may be as high as 10 to 35 per cent of the applied quantity, nitrogen losses from nitrate fertilizers being much higher than from ammonia ones. Consequently, when applying nitrogen fertilizers, one must reduce the nitrification rate as much as possible. In this case, the shorter the time interval during which nitrogen fertilizers are applied before seeding, the lower the nitrogen losses. Surface or shallow placement of solid ammonia and amide fertilizers may entail ammonia losses which increase with pH, fertilizer rate, and moisture content in the soil. Ammonia losses after surface placement of ammonium nitrate and ammonium sulphate usually do not exceed one to three per cent, whereas with high urea rates they amount to 20-30 per cent of the applied nitrogen.

When liquid ammonia fertilizers are used, ammonia losses decrease with increasing incorporation depth and moisture content in the soil. In sandy loam soils, almost no losses occur when aqua ammonia is placed at a depth of 10 to 12 cm and anhydrous ammonia is placed at a depth of 16 cm. In loamy soils, the minimum depth of aqua ammonia placement is 7 to 8 cm and that of anhydrous ammonia placement is 12 to 14 cm.

Phosphorus fertilizers tend to stay concentrated near the site of their application, and their migration over the soil profile is negligible even in light (sandy and sandy loam) soils. Therefore, the probability of phosphorus being leached from the root layer is extremely low.

Potassium is adsorbed in the soil primarily in an ex-

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changeable manner and is firmly retained there, especially in tenacious soils. Some leaching of this nutrient is possible, though, in sandy loam soils.

Fertilizer phosphorus and potassium start being fixed in the soil immediately after their application (within 24 hours), the fixation process being over by the end of the first month. In this case, phosphorus passes into poorly mobile compounds in much greater amounts (50-70%) than potassium. Phosphorus fixation is most pronounced in acid soddy podsolic soils containing a lot of sesquioxides of iron and aluminium. Potassium is fixed to the greatest degree by soils containing minerals of the montmorillonite group. Its fixation is more pronounced in humidified and limed soddy podsolic soils. At a varying moisture content in the soil (alternating desiccation and humidification), the fixation of fertilizer potassium is intensified while that of phosphorus proceeds at the same rate. It should be pointed out that the degree of fixation of fertilizer phosphorus and potassium in tenacious soils after application in autumn and in spring before sowing (planting) is almost the same. As regards phosphorus fertilizers, this applies primarily to powdered water- and citric-soluble forms. Ground phosphate rock is an exception. The earlier it is incorporated into soddy podsolic soils before sowing, the greater amount of available phosphorus is formed in the soil. However, pelletized superphosphate should preferably be applied immediately before or during sowing to minimize phosphorus fixation by the soil. Pelleting of superphosphate provides for a smaller area of contact with the soil, as compared to powdering, which reduces the degree of phosphorus fixation. Yet, if pelletized superphosphate is applied well in advance before sowing, pellets dissolve and phosphorus fixation is intensified.

In the case of shallow placement of phosphorus and potassium fertilizers before sowing in a desiccating soil layer, phosphorus and potassium will not be taken up by crops due to their extremely low mobility and because roots will penetrate deeper into the soil in search for moisture soon after sprouting. When these fertilizers are incorporated by a side dresser, they also often find themselves in the soil layer with insufficient moisture content and, therefore, are less effective than when ploughed down before sowing. This

is why phosphorus and potassium fertilizers, with the exception of their small portions incorporated into seedbeds at sowing, should be placed by a plough with a colter into deeper, moist soil layers which are the main root development zone.

Basal (preseeding) application provides for crop nutrition almost throughout the vegetation period, especially at the intensive growth stage when crops take up most of their nutrients. The basal fertilizer includes most of the nutrients to be applied. It may be incorporated either in autumn or in spring, depending on soil and climatic conditions, fertilizer types and forms, their availability, and other factors of farm management.

The distribution of fertilizers in the soil depends on the implement used for their incorporation (Table 6.7).

Table 6.7. Distribution (approximate) of Inorganic Fertilizers and Lime in the Arable Layer (%) After Incorporation by Various Implements

Implement and placement depth	Soil layer (cm)		
	0-5	5-10	10-20
Plough PN-4-35 with a colter, 20 cm	—	—	100
Plough PN-4-35 without a colter, 20 cm	—	23	77
Heavy disc harrow BDT-2,2 (double-action)	27	45	28
Cultivator with spring tines, 20 cm	32	31	37
Cultivator with universal duckfoot tines, 20 cm	38	34	28
Ditto, 10 cm	84	16	—
Light tined harrow	100	—	—
Heavy tined harrow	97	3	—

Deep placement is achieved by means of a plough with a colter, followed by a plough without a colter and a heavy disc harrow. At the same placement depth, a cultivator with spring tines is more effective than that with universal duckfoot tines. At a loosening depth of 10 cm, about 80 per cent of fertilizer remain in the top layer prone to desiccation, which is to be avoided, especially in the case of phosphorus and potassium fertilizers.

The selection of an optimal schedule of basal application is determined mainly by soil texture, moisture conditions,

and fertilizer properties. Nitrate and ammonium-nitrate forms of nitrogen fertilizers should be applied to soddy pod-solic and grey forest soils, leached and podsolized chernozems with excess and sufficient moisture, in spring to avoid unnecessary nitrogen losses. They are placed during reploughing of autumn-ploughed land or, more commonly, with the aid of a cultivator. In view of the fact that nitrate nitrogen migrates rapidly throughout the soil when it rains, shallow placement of the fertilizer by the cultivator is quite safe. During a warm spring period, ammonia nitrogen converts into the nitrate form almost completely within two weeks and is easily driven downwards by rain or irrigation water. In low-rainfall regions, soils with nonpercolative (non-leaching) regime (ordinary, typical, and southern chernozems, chestnut soils) should be treated with nitrogen fertilizers during autumn ploughing. When incorporated to a shallow depth in spring, they find themselves in the rapidly drying soil layer and become less effective, especially after long spells of dry weather. Sometimes it is recommended to start treating heavy soddy podsolic soils with solid ammonia fertilizers in autumn. In this period, if the temperature is below $10\,°C$, the nitrification process virtually comes to a standstill. However, when the weather changes, nitrification is possible with associated nitrogen losses. Therefore, such soils should also be treated with solid ammonia fertilizers in spring.

In areas with sufficient rainfall, liquid ammonia fertilizers (aqua ammonia, anhydrous ammonia) may be applied to soddy podsolic soils of heavy and medium texture during ploughing in autumn. In any event, phosphorus fertilizers should rather be incorporated deeper, that is, during autumn ploughing or reploughing in spring.

Potassium fertilizers are applied in spring only to the sandy and sandy loam soils of high-rainfall regions (or those under irrigation). Other soils should better be treated during autumn ploughing, especially with chlorine-containing fertilizers. Here, chlorine is leached out of the topsoil layers in autumn and in spring and produces less detrimental effect on chlorophobic crops.

Manure (compost) is incorporated during ploughing in autumn or reploughing in spring. Manure is applied in

spring if by autumn the farm has not been able to accumu-
late it in sufficient amounts, as well as to sandy and sandy
loam soils in view of the possible losses of nitrogen and
potassium.

In arid regions of the country, preference is given to
rotted manure because it desiccates the soil to a lesser extent.
The best for the Non-Black Earth zone is half-decomposed
and even fresh manure if it is applied during autumn
ploughing. The heavy soils of the northern part of the Non-
Black Earth zone require manuring to a shallower depth, as
compared to light soils. When incorporated near the surface
of moist and heavy soils, manure decomposes more quickly
than after incorporation to a greater depth where aeration is
poorer. In arid regions, manure is ploughed down deeper
than in high-rainfall areas.

The unevenness of fertilizer distribution should not exceed
15 to 20 per cent.

The basal fertilizer may be broadcast or applied locally.
At present, the following localized application techniques
are tried.

1. Preseeding band application of the basal fertilizer to
grain crops by special machines of the fertilizer drill type or
combined tillers.

2. Band application of the basal fertilizer during seeding
of grain crops by combined drills or machines combining
fertilizer and seed drilling with other operations.

3. Band application of the basal inorganic fertilizer to
potatoes by combined planters.

The trial results indicate that localized band application
of the basal fertilizer increases the yield by 3 to 23 per cent
as compared to broadcasting. However, when this technique
is used systematically from one year to another with medium
and high rates being applied in crop rotation, its effectiveness
goes down.

In recent years, a great deal of interest has been expressed
in reserve (periodic) application of phosphorus and potassium
fertilizers. This is one of the basal application techniques
residing in that fertilizers are applied a few years in advance
(e.g. 240 kg P_2O_5 per hectare for a period of four years)
rather than each year (e.g. 60 kg P_2O_5 per hectare). There is
no consensus as to the merits of this technique. In some cases,

it is better than annual application, in others, it is as effective as the latter or less. In soils where fertilizer phosphorus is fixed to a great degree and non-exchangeable potassium fixation is pronounced, reserve application is less effective than the annual one.

Reserve application is finding limited uses, primarily in treatment of nurse perennial grass crops, in pasture cultivation, in orchards, and at some farms receiving ample quantities of fertilizers. At farms where little fertilizer is used, it would not be sensible to reserve fertilizers on part of the arable area (except for the cases mentioned above) and disregard other plots for this would decrease the overall effect of fertilizing at the farm as a whole. Potassium fertilizers should not be reserved in sandy and sandy loam soils where potassium may be easily leached out. Bulk application of potassium fertilizers at a high rate may increase the potassium content in the harvested crop (more than 3% K_2O in terms of dry matter) and, thereby, adversely affect animal organisms. Besides, high rates of chlorine-containing potassium fertilizers may lower the quality of chlorophobic crops within the first years after application.

Starter (Drilling) Application. The starter fertilizer is always placed locally in the soil, whereby the utilization factor of phosphorus from superphosphate increases (when applied to grain crops at seeding, the utilization factor may be as high as 40 to 60 and even 80 per cent). The starter fertilizer substantially improves the growth of young plants when they cannot yet fully take up soil-derived phosphorus and renders sprouts more resistant to adverse environmental conditions. The starter application rates are usually small (5 to 25 kg of each nutrient per hectare). This is due to the fact that direct contact (without a soil layer in between) of fertilizers with seeds may inhibit sprouting by high concentrations of their salt solutions and because of the extremely low mobility of phosphorus and potassium after incorporation.

The most sensitive to high soil solution concentrations are maize, flax, carrots, onion, cucumbers, rutabaga, and turnip, potatoes being the least sensitive. Drilling is most effective if the fertilizers and seeds are separated by a layer of soil.

The predominant ingredient of the starter fertilizer is phosphorus, nitrogen being far behind, and potassium often produces no effect whatsoever (except in the case of potassium-loving crops) and may even reduce yields, especially for small-seed crops. The nitrogen of the starter fertilizer applied to grain crops after an adequately fertilized precursor usually does not increase the yield.

Used as starter fertilizer are pelletized single and double superphosphate as well as compound fertilizers (ammophos, diammophos, nitrophos, nitrophoska, nitroammophos, and nitroammophoska). Single fertilizers should not be mixed for drilling because the resulting mixture is often greasy and difficult to drill. Pelletized superphosphate alone is the best for this application. At high rates of the basal fertilizer, the positive effect of the starter fertilizer diminishes or vanishes altogether.

Dressing or Postseeding Application. The results of experiments carried out at research institutions indicate that in most cases involving soils of medium or heavy texture, where the probability of nutrient leaching is low, partial transfer of even nitrogen fertilizers, to say nothing of potassium and phosphorus ones, from basal application to dressing lowers crop yields. This is due to the fact that fertilizers applied on the surface or even by a side dresser during the vegetation period often find themselves in parched soil and, therefore, are far from being fully available. Dressing may produce good results only in the presence of moisture. Particularly undesirable is to dress crops with phosphorus and, in the case of tenacious soils, potassium fertilizers whose migration through the soil is minimal. Postseeding application is worthwhile in the following instances:

1. Dressing of winter crops with nitrogen fertilizers.

2. Dressing of row crops grown on light (sandy and sandy loam) soils with nitrogen and potassium fertilizers with irrigation or in high-rainfall regions.

3. Application of high annual rates of inorganic fertilizers to crops especially sensitive to high salt concentrations.

4. Treatment of fruit and berry plantations as well as permanent cultivated pastures.

5. Treatment of perennial grasses in field crop rotations when phosphorus and potassium fertilizers have not been

applied at full rate to the nurse crop for reasons beyond the farm's control.

6. Dressing of flax at the branching stage if the nitrogen fertilizers to be applied before seeding have not been in sufficient amounts.

Sometimes farmers have to resort to dressing because no fertilizers were available before seeding.

Close-growing crops (winter crops, grasses, flax) are dressed with inorganic fertilizers by the same machines that are used for basal application.

In addition to land machines, agricultural aviation is widely employed.

6.6 Determination of Fertilizer Rates to Be Applied to Farm Crops

Rating of inorganic fertilizers to be applied to farm crops is one of the most important and difficult tasks in agricultural chemistry. Distinction is made between optimal, rational, and maximum rates.

A rate is said to be *optimal* when it ensures a high yield of quality crop at a maximum net return from a hectare with soil fertility being improved or kept at the same level throughout a crop rotation cycle.

As fertilizer rates go up, the return due to yield increase after application of one kilogram of nutrients starts decreasing from a certain level. Therefore, if a farm has little inorganic fertilizers, it is more profitable to apply lower rates to a larger area and to attain a higher gross yield than to apply high rates over a smaller area. However, if a farm applies fertilizers at high rates from year to year and produces high yields while steadily improving the fertility of its fields, a further increase in yield naturally reduces the return due to additional fertilizing. Yet, in this case, more produce is harvested from a hectare, and the cropping intensity increases. Hence the notion of rational rate. By *rational* is meant the rate which ensures, under the specific condition prevailing at a farm, the highest possible yield of crops of top or satisfactory quality from a hectare with drastic improvement of soil fertility that under any circumstances provides for an economic return from the fertilizers.

However, there must be a limit beyond which fertilizing is not worthwhile under certain soil and climatic conditions. Otherwise, farming may become unprofitable, the crop quality may go down, and environmental pollution may occur. Thus, the *maximum* rate ensures the highest possible yield of crops of acceptable quality with the prerequisite that the fertilizers at least pay their way. In view of the importance of attaining the highest yield of crops from unit area, such an approach may be justified in some cases, especially where all farms have sufficient amounts of fertilizer, or in areas where major crops are grown with intensive chemicalization.

6.6.1 Determination of Fertilizer Rates, Based on Direct Use of Field Experiment Results and Agrochemical Charts

Having summarized the results of field experiments, research institutes of the USSR offer recommendations for application of average fertilizer rates to various crops grown at farms of a particular region.

Given by way of example in Table 6.8 are fertilizer rates for soddy podsolic soils in regions where chemicalization is practised on a wide scale. The recommended rates of phos-

Table 6.8. Approximate Fertilizer Rates for Treatment of Some Crops Grown on Soddy Podsolic Loamy Soils

Crop	Manure (t/ha)	Fertilizers (kg/ha)		
		N	P_2O_5	K_2O
Winter cereals:				
on cropped fallow	20-30	100-120	80-100	40-60
after clover with timothy	—	70-100	100-120	100-120
Spring cereals	—	80-120	80-100	60-80
Fibre flax after clover	—	20-40	60-90	80-100
Potato	30-40	100-120	80-100	100-120
Maize and other ensilage crops	30-40	100-120	80-100	80-100
Fodder root crops	30-40	180-220	120-150	180-220
Cabbage	30-40	150-180	80-100	150-180

phorus and potassium fertilizers are adjusted according to
the availability of mobile forms of phosphorus and potas-
sium in the soil, using approximate correction factors (Ta-
ble 6.9). Nitrogen fertilizer rates are usually adjusted accord-

Table 6.9. Correction Factors to Fertilizer Rates, with Account Taken of
the Content of Mobile Phosphorus and Potassium in the Soil

Nutrient content in the soil, according to chart	Grain crops, grasses, flax, row crops	Vegetables
Nitrogen fertilizers		
P_2O_5		
Very low	1.2	—
Low	1.1	1.2
Medium	1.0	1.1
Moderately high	0.9	1.0
High	0.8	0.9
Very high	0.7	0.8
Phosphorus and potassium fertilizers		
P_2O_5 or K_2O		
Very low	1.5	—
Low	1.2-1.3	1.5
Medium	1.0	1.2-1.3
Moderately high	0.7-0.8	1.0
High	0.4-0.6	0.7-0.8
Very high	0.1-0.3	0.4-0.6

ing to the phosphorus chart (it is phosphorus that is most
often present in the soil in the minimal amount after nitro-
gen) because no nitrogen charts are available. At a correction
factor of unity, the rate is taken without any adjustment.
Row fertilizer rates are always applied without any cor-
rection factor.

In spite of the highly promising nature of this method
for determining fertilizer rates, it cannot be completely
relied upon at present because of lack of sufficient data.

The rates recommended in Table 6.8 have been calculated
to ensure the following yields: 30 to 35 cent/ha of grain, 6
to 8 cent/ha of flax fibre, 200 to 250 cent/ha of potatoes,
400 to 500 cent/ha of root crops, 350 to 400 cent/ha of maize
forage, and 500 to 600 cent/ha of cabbage.

If the recommended fertilizer rates have been derived from

a field experiment on a soil with a definite content of mobile phosphorus and potassium forms, in practical application they must be adjusted according to the class of soil in the field to be fertilized. The adjustment is done as follows. If the class of the soil of interest in terms of mobile phosphorus (or potassium) content differs from that of the soil of the experimental field by a factor of 1 or 2, the phosphorus (or potassium) rate is to be changed by ± 25 and ± 50 per cent, respectively, while the nitrogen rate must be changed by ± 10 or ± 20 per cent. The nitrogen rate is usually adjusted with respect to the nutrient whose content in the soil is the lowest after nitrogen (phosphorus in the case of soils of medium and heavy texture, potassium in the case of light soils) because no mobile nitrogen charts are currently available.

The yield ensured by the fertilizer rate used in the experimental field must be brought into compliance with the actual conditions. It has been established, for example, that fertilizers are more effective on small plots, as opposed to large fields (by 30% for grain crops and 50% for potatoes). For instance, in the Latvian SSR, the effectiveness of fertilizers in the field is lower by 30 per cent on the average than in the experiment, while in the German Democratic Republic, where farming practices are rather advanced, it is lower by an average of 20 to 25 per cent.

Fertilizer rates are also determined by mathematical processing of the field experiment data. In this case, multifactorial experiments yielding a wealth of information are most valuable. The mathematical processing of multifactorial experiment data comprises the following steps: (1) processing of the experimental results by the multiple regression method; (2) selection of a mathematical model; (3) generation of the derived function; and (4) calculation of the factors of correlation among different indicators.

6.6.2 Calculation Methods Used to Determine Fertilizer Rates

Determination of Fertilizer Rates to Attain Estimated Yields (Nutrient Balance Method). In this method, use is made of reference data concerning nutrient removal per unit

main product (per 10 or 100 centners) with due account for by-products, namely, factors of nutrient utilization from the soil, fertilizer, afterharvesting and root residues (usually legumes). The missing soil-derived nutrients are made up by application of organic and inorganic fertilizers to attain the estimated yield. The approximate utilization factors that can be used in calculations of fertilizer rates for soddy podsolic and grey forest soils are given in Table 6.10.

Table 6.10. Factors of Nutrient Utilization from Soils and Fertilizers (%) (for soddy podsolic and grey forest soils)

Crop	From the soil (at medium and higher nutrient contents)*		From inorganic fertilizers within the 1st year			From organic fertilizers within the 1st year		
	P_2O_5	K_2O	N	P_2O_5**	K_2O	N	P_2O_5	K_2O
Cereals, annual and perennial grasses	5	10	50-60	15-25	40-50	20	30	40-50
Flax	3	5	30-40	10-15	30-40	—	—	—
Row crops (potato, fodder root crops, ensilage crops)	5	20	60-70	20-25	50-70	20-25	30	50-60
Cabbage	5	20	60-70	20	60-70	20-25	30	60
Carrot, table beet, tomato	5	10	50-60	15-20	50-60	20	20	50
Cucumber	3	5	30-40	10-15	30-40	15-20	20	30

* At low nutrient contents in the soil, the utilization factors must be increased 1.5- to 2-fold.
** In the case of drilling, 30-60% P_2O_5 from superphosphate are utilized.

For fertilizer aftereffect, see Table 6.4. The utilization factor of the easily hydrolyzable nitrogen from the soil is taken equal to 0.2 (or 20%).

Different methods for determining nutrients in soils must be based on their own soil-derived nutrient utilization factors (see Table 6.3).

Let us now illustrate the nutrient balance method by an example.

The potato yield on soddy podsolic moderately loamy soil is estimated at 200 centners per hectare. According to the two-year-old chart, such a soil contains 5-10 mg P_2O_5 and 8-12 K_2O per 100 g of the soil (Kirsanov's method). Organic fertilizers are to be applied at a rate of 30 t/ha. According to agrochemical analysis data, they contain 0.3% N, 0.15% P_2O_5, and 0.4% K_2O.

Potatoes are grown in the crop rotation link: barley + + perennial grasses, 1st-year grasses, 2nd-year grasses, winter wheat, and potatoes. Barley was treated with $N_{80}P_{160}K_{180}$ (with the perennial grasses receiving phosphorus and potassium), and winter wheat was treated with $N_{50}P_{80}K_{80}$. The annual yield of perennial grass hay was 40 centners per hectare.

Determined from this data must be the fertilizer rate to attain the estimated potato yield.

100 centners of potatoes with the haulm remove 60 kg N, 20 kg P_2O_5, and 90 kg K_2O (Table 6.2). Consequently, the 200-centner yield will remove 120 kg N, 40 kg P_2O_5, and 180 kg K_2O.

Since the aftereffect of fertilizers is usually taken equal to a maximum of two years, in our example only the aftereffect of the fertilizers applied to winter wheat is determined. If the results of agrochemical soil analysis for mobile phosphorus and potassium content had covered the current year (which, in fact, is not so), the aftereffect of the phosphorus and potassium of the fertilizers applied to potatoes earlier could have been ignored. The aftereffect of the nitrogen from organic fertilizers and afterharvesting and root residues of legumes must be taken into account in all cases in view of the fact that charts indicating the content of mobile nitrogenous compounds in the soil are not prepared.

In our example, the overall yield of clover and timothy hay over two years was 80 centners per hectare. As can be inferred from experimental data, one ton of hay leaves in the field 10 to 15 kg of nitrogen per hectare in the form of afterharvesting and root residues. Hence, such residues of perennial grasses will contain about 120 kg of nitrogen per hectare. The first crop grown after grasses (in this case, winter wheat) may take up about 25 per cent, or 30 kg, of nitrogen from afterharvesting and root residues, while the

second crop (potato) will take up about 15 per cent, or 18 kg, of nitrogen.

The utilization of nutrients from the soil is determined as follows. The soil contains (according to the chart) an average of 7 mg P_2O_5 and 10 mg K_2O per 100 g. Hence, a hectare of the topsoil contains 210 kg P_2O_5 and 300 kg K_2O. Potatoes may take up from the soil about 5 per cent mobile phosphorus (10 kg P_2O_5) and 20 per cent mobile potassium (60 kg K_2O) (Table 6.10). Determination of nitrogen uptake from the soil is more difficult. This can be done by two methods.

Method 1: nitrogen removal is determined with respect to the nutrient whose content in the soil is the lowest after nitrogen. For example, the nutrient following nitrogen in the lowest content in soddy podsolic loamy soil is phosphorus. The latter is taken up from the soil in an amount of 10 kg, which may provide for a potato yield of 50 centners per hectare (the P_2O_5 removal by one centner of tubers together with haulm amounts to 0.2 kg). In the case of a sandy loam or sandy soddy podsolic soil, where the potassium content is the second lowest, the estimated yield should be determined with respect to potassium. A tuber yield equal to 50 centners per hectare will remove 30 kg of nitrogen from the soil, because we know from reference data that 100 centners of tubers with haulm remove 60 kg of nitrogen.

Method 2: nitrogen removal from the soil is determined from the approximate content of easily hydrolyzable nitrogen in it. If no agrochemical analysis data are available, it may be assumed that tenacious soddy podsolic soils of medium fertility contain about 4 to 6 mg of easily hydrolyzable nitrogen, soils of moderately high fertility contain 6 to 8 mg of this nitrogen, and those of high fertility contain 8 to 10 mg of hydrolyzable nitrogen per 100 g of soil. In our example, 100 g of soil contain nearly 5 mg of easily hydrolyzable nitrogen. This corresponds to 150 kg of nitrogen in a hectare of the topsoil (5 mg $\times$ 30). Potatoes may take up about 20 per cent, or 30 kg, of easily hydrolyzable nitrogen from the soil.

The overall procedure of calculating the annual rate of inorganic fertilizers to be applied to potatoes may be represented in the following manner:

Indicators	N	P_2O_5	K_2O
Nutrient removal by the estimated yield of 200 cent/ha (kg)	120	40	180
Aftereffect of the fertilizers $(N_{60}P_{80}K_{80})$ applied earlier (kg)	—	8 (10%)	16 (20%)
Aftereffect of the nitrogen in afterharvesting and root residues of perennial grasses (kg)	18	—	—
Nutrients taken up from the soil (kg)	30	10	60
Nutrients received by a hectare of the soil from 30 t of organic nutrients (kg)	90	45	120
Organic fertilizer nutrient utilization factors within the 1st year (%)	20	30	50
Nutrients taken up from the applied organic fertilizers within the 1st year (kg)	18	13	60
Inorganic fertilizer nutrient requirements (kg)	54	9	44
Inorganic fertilizer nutrient utilization factors within the 1st year (%)	60	20	60
Nutrients to be applied with inorganic fertilizers with due account for the utilization factors (kg/ha)	90	45	70

The calculated rates are usually rounded off to within 5 or 10 kg.

The calculated rates of the nutrients to be applied with inorganic fertilizers can be expressed in terms of:

(a) physical fertilizer rates:

ammonium nitrate $= \dfrac{90 \times 100}{34} = 265$ kg, or 2.7 cent/ha,

where 34 is the nitrogen content in ammonium nitrate (%);

ordinary superphosphate $= \dfrac{45 \times 100}{20} = 225$ kg, or 2.3 cent/ha;

potassium chloride $= \dfrac{70 \times 100}{60} = 117$ kg, or 1.2 cent/ha;

(b) standard fertilizer rates:

ammonium sulphate $= \dfrac{90 \times 100}{20.5} = 440$ kg, or 4.4 cent/ha.

superphosphate $= \dfrac{45 \times 100}{18.7} = 241$ kg, or 2.4 cent/ha;

potassic salt $= \dfrac{70 \times 100}{41.6} = 168$ kg, or 1.7 cent/ha.

Determination of Inorganic Fertilizer Rates to Attain the Estimated Yield Increase. The procedure is this. Knowing the yields of a particular crop under given soil and climatic conditions without fertilizing (from the results of experiments carried out by the agrochemical service), one can determine the yield increase due to organic and inorganic fertilizers. The established inorganic fertilizer rates are adjusted depending on the mobile nutrient content in the soil, using appropriate correction factors (Table 6.9).

Consider now the method for determining inorganic fertilizer rates in the context of the preceding example. The potato yield without fertilizing is 50 cent/ha. The estimated yield increase is 150 centners per hectare. The nutrient removal by 100 centners of tubers together with haulm amounts (according to reference data) to 60 kg N, 20 kg P_2O_5, and 90 kg K_2O. The calculations are made in the following manner:

Indicators	N	P_2O_5	K_2O
Nutrient removal ensuring the estimated yield increase of 150 cent/ha (kg)	90	30	135
Aftereffect of the fertilizers $(N_{50}P_{80}K_{80})$ applied earlier (kg)	—	8	16
Aftereffect of the nitrogen in afterharvesting and root residues of perennial grasses (kg)	18	—	—
Nutrients taken up from 30 t of organic fertilizers within the 1st year (kg)	18	13	60
Inorganic fertilizer nutrient requirements (kg)	54	9	59
Inorganic fertilizer nutrient utilization factors within the 1st year (%)	60	20	60
Nutrients to be applied with inorganic fertilizers with due account for the utilization factors (kg)	$\frac{54 \times 100}{60} = 90$	$\frac{9 \times 100}{20} = 45$	$\frac{59 \times 100}{60} = 100$

Nutrients to be ap-
plied with correction
for   soil   fertility
(Table 6.9) (kg) $90 \times 1 = 90$ $45 \times 1 = 45$ $100 \times 1 = 100$

**Determination of Inorganic Fertilizer Rates, Based on
Standard Nutrient Balance per Crop Rotation Cycle.** The
balance of soil nutrients has credit and debit sides. The
credit side includes the nutrients received by the soil from
fertilizers, seeds, and the atmosphere (including the nitro-
gen supplied by the nodule bacteria of legumes and free-
living nitrogen-fixing bacteria).

The debit side of the balance includes yield removal of
nutrients, losses of soil-derived and fertilizer nutrients due
to surface runoff, leaching (infiltration), and volatilization
(e.g. nitrogen losses due to denitrification).

Distinction is made between complete, or ecological,
balance (sometimes also referred to as biological), taking
into account all credit and debit items, and simplified,
or economic, balance, taking into account only the nutri-
ents received by the soil from fertilizers and the additional
amount of nitrogen supplied by legumes (left by the latter
in the soil after the rest has been removed by the harvested
crops) as well as yield removal and possible losses from fertil-
izers. In the economic balance, other instances of nutrient
supply (with precipitations, seeds, from free-living nitrogen-
fixing bacteria) and removal (nutrient losses from the soil)
are disregarded because they are assumed to be equivalent.
The balance may be intensive (positive), if the supply of
nutrients into the soil exceeds the yield removal and losses
from the soil and fertilizers, extensive (negative), if the
nutrient removal and losses exceed supply, and zero, if the
supply and removal are equivalent.

In farming practice, when a fertilizer system is drafted
for crop rotation, the economic balance is usually involved.
It may be expressed in terms of each nutrient, in relative
(percentage of yield removal) and absolute (kg/ha) quanti-
ties. The dynamic variations in balance indicators are defined
as "balance intensity variations".

The percentage of individual credit and debit items in
the balance determines its structure.

The method under consideration is based on a nutrient

12*

balance per crop rotation cycle. Table 6.11 gives a tentative standard nutrient balance for soddy podsolic and grey forest soils. One can also use a quantity reciprocal of the standard balance items, i.e. the coefficient of yield removal of soil-derived and fertilizer nutrients (Table 6.11).

In the literature, the relative balance expressed as percentage of yield removal, or balance intensity (standard

Table 6.11. Tentative Standard Nutrient Balance per Crop Rotation Cycle (% of yield removal) and Yield Removal Coefficients (% of nutrients in applied fertilizers), Depending on Nutrient Contents in Soddy Podsolic and Grey Forest Soils

Class of soil	Mobile phosphorus and potassium content in the soil	Nutrients received by the soil from fertilizers over the crop rotation period (% of yield removal)			Yield removal coefficients (%)		
		N*	P_2O_5	K_2O	N*	P_2O_5	K_2O
1-2	Very low and low	120-130	200-250	130-150	85-75	50-40	80-65
3	Medium	120-130	170-200	110-130	85-75	60-50	90-80
4	Moderately high	110-120	140-170	80-100	90-85	70-60	125-100
5	High	100-110	100-140	60-80	100-90	100-70	170-125
6	Very high	80-100	70-100	40-60	125-100	140-100	250-170

* Depending on the mobile phosphorus content in the soil.

balance), is sometimes referred to as "return coefficient" or "return factor" and written as a decimal fraction. For example, if the standard balance (relative balance) is 120 per cent with respect to nitrogen and 200 per cent with respect to phosphorus, the corresponding return coefficients, or factors, will be 1.2 and 2.0. The nutrient removal coefficient is occasionally referred to by some authors as the "balance coefficient". It indicates the percentage of yield removal with respect to the nutrient amount received by the soil from fertilizers. It is usually defined in the context of a crop rotation cycle. For instance, if this coefficient equals 100 with respect to any nutrient, then the supply of the nutrient with fertilizers and its yield removal compensate

each other. If it is less or more than 100, the nutrient supply with fertilizers either exceeds the yield removal or falls short of it.

When a standard balance is drawn up (Table 6.11), the assumption is that, in order to maintain the original nitrogen, phosphorus, and potassium contents in the soil, it is sufficient to apply 120-130% N, 100% P_2O_5 and 100 % K_2O with organic and inorganic fertilizers, with respect to yield removal. The standard balance of Table 6.11 is intended to maintain the nitrogen content in the soil at a medium or increased level, the phosphorus content at a high level, and the potassium content at an increased level. The standard balance and coefficient of yield removal per crop rotation cycle are valuable tools for keeping the soil fertile (increasing soil fertility or maintaining it at a certain level) and permit agronomists to creatively utilize land resources.

In this case, one must also resort to coefficients of nutrient distribution from one year to another (normally, a span of not more than three years is taken). These coefficients (Tabbe 6.12) are derivatives from fertilizer nutrient

Table 6.12. Approximate Coefficients of Distribution of Fertilizer Nutrients and Nitrogen from Afterharvesting and Root Residues of Legumes (%)

Year of fertilizer effect	Organic fertilizers			Inorganic fertilizers			Nitrogen from leguminous residues
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	
1st	40	65	80	100	55	70	50
2nd	40	25	20	—	30	30	30
3rd	20	10	—	—	15	—	20
Total	100	100	100	100	100	100	100

utilization factors. The amount of each nutrient over a period of three years is expressed as 100 per cent.

Consider now a method for determining the rates of inorganic fertilizers to attain the estimated potato yield of 200 centners per hectare, just as in the methods described above.

When humus-rich soils and soils in arid regions (where

the fertilizer effectiveness is very low) receive insufficient amounts of inorganic and organic fertilizers, nitrogen, phosphorus, and potassium balances are drawn up in a different

Indicators	N	P_2O_5	K_2O
Nutrient removal by the estimated yield (kg)	120	40	180
Nutrient balance per crop rotation cycle (% of yield removal) or yield removal coefficients (%)	130 75	200 50	120 85

Fertilizer nutrient requirements to attain the estimated yield, with corrections for the nutrient balance or yield removal coefficients (kg/ha)

$$\frac{120 \times 130}{100} = 156 \qquad \frac{40 \times 200}{100} = 80 \qquad \frac{180 \times 120}{100} = 216$$

or

$$\frac{120 \times 100}{75} = 160 \qquad \frac{40 \times 100}{50} = 80 \qquad \frac{180 \times 100}{85} = 212$$

(Both correction factors give almost the same results)

	N	P_2O_5	K_2O
Aftereffect of afterharvesting and root residues of perennial grasses (containing about 120 kg N per ha) (kg)	36	—	—
Aftereffect of inorganic fertilizers $(N_{50}P_{80}K_{80})$ (see Table 6.12) (kg)	—	24	24
Effect of 30 t of organic fertilizers $(N_{90}P_{45}K_{120})$ within the 1st year (see Table 6.12) (kg)	36	29	96
Inorganic fertilizer nutrient requirements (kg)	$156 - 72 = 84$	$80 - 53 = 27$	$216 - 120 = 96$
Coefficients of distribution within the 1st year (%)	100	55	70

Inorganic fertilizer nutrient requirements with due account for distribution coefficients (kg/ha)	$\frac{84 \times 100}{100} = 84$	$\frac{27 \times 100}{55} = 50$	$\frac{96 \times 100}{70} = 140$

manner (see "Preparation of Fertilizer System for Crop Rotation").

Integrated Method for Determining Fertilizer Rates. This method is based on (1) the estimated yield, (2) nutrient content in the soil and its state of cultivation, (3) the results of field experiments with fertilizers and the experience of advanced farms, (4) calculations, for want of experimental data, (5) interpolation and extrapolation of field experiment results, and, to some extent, (6) biological characteristics of the precursor and (as stated in some recommendations) soil texture.

One of such recommendations as regards fertilizer rates for the soddy podsolic soils of the north-western part of the RSFSR has been prepared at the North-Western Research Institute of Agriculture (Table 6.13).

The rates of Table 6.13 are finally adjusted, using Table 6.14, depending on local fertilizer application conditions.

In our example, the inorganic fertilizer rate to attain the estimated potato yield of 200 centners per hectare is, according to Table 6.13, $N_{70}P_{70}K_{60}$ (with 20-30 t of manure being applied to a hectare). After the appropriate corrections, the final application rates will be: 70 kg/ha N (no adjustment), 50 kg P_2O_5 (30% correction of the 70 kg rate for aftereffect of the previously applied phosphorus fertilizers), and 60 kg K_2O (no adjustment because of the weak aftereffect of the previously applied potassium fertilizers).

In the final analysis, the calculation and integrated methods for determining fertilizer rates to attain the estimated potato yield of 200 centners per hectare have produced the following results: 70-90 kg N, 45-50 kg P_2O_5, and 60-140 kg K_2O.

Every method for determining fertilizer rates must be used under appropriate circumstances, and the validity of the established rates to be applied to individual crops in

Table 6.13. Tentative Fertilizer Rates (kg active ingredient/ha) for Farm the RSFSR (according to Sapozhnikov and Kornilov)

Estimated yield (cent/ha)	Ma-nure (t/ha)	Nitrogen fertilizers at the following state of soil cultivation		
		high (60)	me-dium (40-60)	low (20-40)
Barley (grain)	20-25	—	40	50	80
	35-40	—	70	90	x
Oat (grain)	20-25	—	30	50	70
	35-40	—	50	80	x
Winter rye (grain) on cropped fallow	20-25	20	15	30	60
	30-35	40	40	60	x
Winter rye on clean or clover fallow	20-25	20	20	30	40
	30-35	20	40	50	x
Pea and vetch (seeds)	18-20	—	20	30	40
Sunflower for silage (forage)	300-350	30-40	40	60	90
	500-550	40-50	80	100	x
Annual legume-grass mixture (forage)	150-200	—	—	20	30
	250-300	—	30	50	60
Clover and 1st-year timothy with predominance of clover (hay)	30-35	—	—	20	30
	40-50	—	20	40	40
Perennial grasses with predominance of cereals (hay)	30-35	—	20	30	50
	40-50	—	40	50	70
Cultivated pastures in the 1st year, covered with legume-grass mixture		40-60	20	30	40
Cultivated pastures in the subsequent years (fodder units)	2500-3000		60	80	120
	4000-5000		160	200	240
Fodder beet	200-300	30-40	40	60	80
	400-500	50-60	70	110	x
Flax (fibre)	5-6	—	30	40	50
	8-10	—	50	60	x
Potato	180-200	20-30	60	70	80
	260-300	40-50	80	90	100
Middle and late cabbage	300-400	40-50	40	60	90
	500-600	50-60	120	160	x
Table carrot and beet	250-300	—	80	100	x

Note: x — no high yields are planned before cultivating the soil; r — row

Crops Grown on the Soddy Podsolic Soils of the North-Western Part of

Phosphorus fertilizers at the following P_2O_5 contents (mg/100 g)					Potassium fertilizers at the following K_2O contents (mg/100 g)				
> 25	15.1-25	10.1-15	5.1-10	< 5	> 25	17.1-25	8.1-17	4.1-8	< 4
10r	30	50	70	80	40	50	60	70	80
30	70	90	120	130	70	80	90	110	130
10r	30	40	60	70	30	40	50	60	70
10r	50	60	100	120	50	60	70	100	120
20	30	50	70	90	20	30	40	70	90
40	60	80	100	110	40	50	60	90	110
20	30	50	70	100	20	30	40	70	90
50	70	90	110	130	50	60	70	90	110
20	40	60	90	110	30	40	50	80	100
30	40	50	60	70	40	50	60	80 ⁻	100
70	80	90	100	120	80	100	120	140	160
30	40	50	80	100	20	30	40	60	70
50	60	80	100	120	30	40	50	70	90
—	20	40	50	70	—	20	40	50	60
20	40	60	70	80	40	50	60	60	70
—	20	30	40	50	—	20	30	40	50
20	40	60	80	100	30	40	50	60	80
60	90	100	120	140	40	60	80	120	140
—	40	50	60	70	—	20	40	50	60
50	60	80	90	100	40	50	60	80	100
20	30	40	60	80	40	50	60	70	80
60	70	80	100	120	90	100	110	120	140
30	50	70	90	110	40	50	70	80	100
60	80	100	120	140	60	70	80	100	120
30	40	50	70	90	40	50	60	80	100
50	60	70	90·	100	60	70	80	100	120
40	50	60	80	100	40	60	80	100	120
90	110	120	140	170	80	100	120	140	160
40	60	80	100	120	70	90	110	140	160

fertilizer

Table 6.14. Adjustment of Fertilizer Rates, Depending on Application Conditions (according to Sapozhnikov and Kornilov)

20-30% increase (primarily on soils of low state of cultivation)	20-30% decrease

Nitrogen Fertilizers

Application of organic fertilizers with a low content of available nitrogen; on newly reclaimed podsolic soils	Crops grown on lush clover fallow, after high-yielding alfalfa either on highly cultivated soddy gley or dark soils; in the case of perennial grass cover

Phosphorus Fertilizers

Crops grown on newly reclaimed soils with an extremely low content of easily soluble phosphates and moderatery high aluminium and iron contents; in the case of perennial grass cover; application of phosphorus fertilizers in the northern part of the Non-Black Earth zone	After heavy application of phosphorus fertilizers in the preceding years; heavy manuring (with a normal phosphorus content in the manure); local application of phosphorus fertilizer

Potassium Fertilizers

On peaty soils; at high nitrogen fertilizer rates	On clayey soils; after many years of heavy application of potassium fertilizers; heavy manuring

a rotation cycle must be verified with respect to the nutrient balance per cycle, which is indicative of the possible yield and soil fertility changes.

6.7 Treatment of Individual Crops in Field and Fodder Crop Rotations

6.7.1 Treatment of Winter Cereals

Winter wheat is one of the main food crops. It is grown primarily in Ciscaucasia and the Ukrainian SSR, where more than 70 per cent of all winter wheat fields are located. This crop is also grown over a vast area in the Central Black

Earth zone and in the Non-Black Earth zone of the European part of the RSFSR.

Winter rye is cultivated in the North-Western, Central, Volga-Vyatka, Central Black Earth, Volga, Ural, and Western Siberian regions, and also in Belorussia, the Ukraine, and the Baltic republics.

Winter wheat and rye have fibrous roots localized predominantly in the topsoil. Winter wheat tillers in autumn and in spring, while winter rye does so primarily in autumn. Winter wheat grows poorly on acid soils and thrives on soils close to neutral and neutral soils. Winter rye is less demanding than other crops as far as soil fertility is concerned. It may be grown on light soils and highly acidic soils. Rye grows well on soils of the pH range from weakly acidic to weakly alkaline and takes up nutrients more vigorously from difficulty available soil compounds. Light sandy and sandy loam soils are ill suited for winter wheat. Winter rye is less demanding as regards its precursors than winter wheat. Ten centners of winter wheat grain with straw remove an average of 35 kg N, 12 kg P_2O_5, and 26 kg K_2O, the respective uptake rates for winter rye being 30, 12, and 28 kg. Hence, winter wheat requires more nitrogen.

Nutrient uptake by winter cereals is by and large over at the flowering stage (Table 6.15).

Table 6.15. Nutrient Uptake by Winter Cereals
(% of the maximum yield removal)

Development stage	Winter rye			Winter wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Tillering (in autumn)	56	49	63	32	20	23
Shooting	76	58	82	56	37	78
Flowering	93	78	99	85	79	100
Gold ripeness	100	100	100	100	100	84

The nutrient uptake is most intensive at the tillering and shooting stages. Adequate nutrient supply to the crops at these stages of development is of paramount importance.

In the Non-Black Earth zone of the European part of the USSR, the most common precursors of winter cereals are

cropped fallows (vetch with oat, pea with oat) or 1st- and 2nd-year perennial grasses. In the Central Black Earth zone and Ciscaucasia, winter cereals are grown on clean, cropped fallows, after perennial grasses and other non-fallow precursors (maize for silage, barley, and winter crops). In steppe regions, the main precursors of winter cereals are clean fallows. The winter cereals sown on clean fallow are better supplied with moisture and nutrients and are under better phytosanitary conditions than after other precursors.

Winter cereals respond well to organic fertilizers with a higher return than in the case of spring cereals. Application of 20 tons of manure per hectare to winter cereals ensures a grain yield increase of about 7 cent/ha on soddy podsolic soils, 5 to 6 cent/ha on grey forest soils and leached chernozems, and about 3 cent/ha on ordinary and southern chernozems. Winter cereals are usually treated with organic fertilizers at rates ranging from 20 to 30 t/ha. They are applied either to clean fallow or to the fallow crop. If the precursor is harvested early, organic fertilizers are applied directly to the winter crops during ploughing. Winter cereals and fallow crops should be treated with half-decomposed manure. If sowing of winter cereals is preceded by surface cultivation of the soil, manure must be incorporated during deep ploughing in autumn under the fallow crop.

The effect of inorganic fertilizers on the yield of winter cereals is largely dependent on soil and climatic conditions.

Phosphorus and potassium fertilizers must be ploughed down. Only a small amount of phosphorus fertilizers, in the neighbourhood of 10 to 15 kg P_2O_5 per hectare, is left for drilling. If soil cultivation for winter cereals is restricted to the surface, phosphorus and potassium fertilizers should better be applied to the fallow crop with winter cereals in mind. After clean fallow, leguminous grasses, and pulses, the effect of phosphorus and potassium fertilizers on winter crops becomes more pronounced, while that of nitrogen fertilizers diminishes. Application of the right forms of phosphorus and potassium fertilizers is conducive to sugar accumulation in young plants and increases their winter hardiness and lodging resistance.

Nitrogen fertilizers are most effective on soils with low fertility and also in the case of a brief interval between har-

vesting of the preceding crop and sowing of winter cereals, when the soil has no time to accumulate a sufficient amount of inorganic nitrogen. According to the Don Research Institute of Agriculture, a metre-thick layer of chernozem over a hectare of clean fallow accumulates 1000 to 1500 tons of productive moisture and up to 150-200 kg of nitrates by the time winter wheat is sown. After non-fallow precursors (ear grasses and sunflower), the productive moisture content is virtually nil, while that of nitrates is only 30 to 40 kg or, in other words, five times lower. Basal application of nitrogen fertilizers to winter cereals is carried out with the aid of a plough, a cultivator, or a disc harrow. Excessive nitrogen uptake by the crops in autumn reduces sugar accumulation in them and lowers their winter hardiness. However, nitrogen deficiency, too, adversely affects the development of winter crops during this period. Therefore, when winter cereals are sown after non-fallow precursors or cropped fallows that have received small amounts of organic fertilizers, nitrogen fertilizers must be placed before sowing in an amount one third of the total nitrogen rate but, as a rule, not more than 60 to 70 kg/ha. When winter crops are sown on clean fallow, after high-yielding leguminous perennial grasses and pulses, and on heavily manured cropped fallow, more often than not there is no need to apply nitrogen before sowing. When the fallow occupied by high-yielding perennial leguminous (legume-cereal) grasses is turned over early and the weather is fair, their afterharvesting and root residues mineralize at a fast rate, and the soil accumulates enough inorganic nitrogen. In this case, the yield of winter crops may be as high as when they are grown on clean fallow. For late ploughing of fallow occupied by perennial grasses, the time interval between tillage and sowing of winter crops becomes shorter, and the decomposition of afterharvesting and root residues is slow, especially at low temperatures and excess moisture. Under such conditions, winter crops may suffer from nitrogen deficiency in autumn, and this nutrient must be made up by placement of inorganic fertilizers. As regards the rate of nitrogen to be applied to winter crops before sowing, its proper selection is extremely important for regions with cold winters, where the danger of their winter killing is particularly serious. We are speaking primarily

of the Non-Black Earth zone. In regions with short mild winters, where significant nitrogen losses from the soil due to leaching are ruled out, it is recommended to place nitrogen at full rate shortly before sowing. This applies to some parts of the Central Black Earth zone and Ciscaucasia. If spring arrives at a rapid pace and the soil dries quickly, broadcast dressing with nitrogen fertilizers may be less effective in comparison with incorporation of nitrogen at full rate before sowing.

The rates of nitrogen fertilizers to be applied to winter cereals before seeding are determined from the estimated yield, nitrogen accumulation in the crops in autumn, at the tillering stage (see Table 6.15), the precursor and the amount of fertilizer it has received. A tentative nitrogen rate to be applied to winter wheat on soddy podsolic soils is given in Table 6.16. If nitrogen is placed at sowing in rows as

Table 6.16. Rates (kg/ha) of Nitrogen Applied As Basal Fertilizer to Winter Wheat on Soddy Podsolic Soils (according to Demin)

Precursor	30 cent/ha		40 cent/ha		50 cent/ha	
	total N rate	including basal fertilizer	total N rate	including basal fertilizer	total N rate	including basal fertilizer
Cropped fallow (vetch-oat, pea-oat)	90	40	140	60	180–200	70
Cropped fallow + manure, 30 t/ha	60	0-10	120	25	170	40
Perennial grasses (clover + timothy), hay yield 40 cent/ha	40	0-15	100	30	150	40

part of a compound fertilizer, the tabulated rates of nitrogen application before sowing must be reduced by a certain amount. Hence, in autumn (basal + row fertilizer), nitrogen is applied in an amount of 20 to 40 per cent of its overall rate, that is, about 30 per cent.

Drill fertilizing of winter cereals is an important farming procedure. It is based on phosphorus primarily and on nitrogen to a lesser extent, potassium producing virtually no

positive effect. The effect of nitrogen applied at sowing becomes manifest usually after non-fallow precursors, when the soil is depleted of inorganic nitrogen. Recommended for drilling is P_{10} in the form of pelletized superphosphate or $N_{10}P_{10}K_{10}$ and $N_{10}P_{10}$ in the form of compound fertilizers. At higher rates, the return from one kilogram of the active ingredient is lower. Heavy application of nitrogen and potassium fertilizers in the row at sowing may reduce the germination rate of seeds because of the high salt concentration. A summary of Geographic Network data indicates that row application of 50 kg/ha of ordinary pelletized superphosphate (10 kg P_2O_5 per ha) to winter wheat at sowing increases the yield by 3.4 cent/ha on soddy podsolic soils, 2.8 cent/ha on grey forest soils, 1.8 cent/ha on ordinary, southern, and leached chernozems, and 3.7 cent/ha on calcareous chernozems. The return per centner of superphosphate is 3.6 to 7.4 centners of grain. This is a very high return from fertilizers. True, such yield increases are ensured by row fertilizers on soils deficient in mobile phosphorus and when low rates of phosphorus fertilizers are applied before sowing.

At present, a wealth of data covering all soil and climatic zones of the USSR are available, attesting to the fact that only nitrogen fertilizers are effective in the dressing of winter crops in spring. The effect produced by phosphorus and potassium fertilizers in this case is so insignificant that the expense involved in their application is not justified. The effectiveness of nitrogen dressing of winter cereals diminishes from north southwards and towards south-east, that is, with decreasing moisture content in the soil. The average grain yield increase in the Soviet Union, provided by application of 30 kg N per hectare to dress winter crops in spring, is about 3 cent/ha, the yield increase on soddy podsolic soils being 5 to 6 cent/ha. The highest grain yield increases due to nitrogen dressing of winter crops in spring on the soddy podsolic soils of the Non-Black Earth zone can be explained by that plants weakened after wintering require nitrogen to resume active growth. By that time, the nitrogen of inorganic fertilizers, even when applied before sowing, migrates from the root zone into the underlying soil layers, driven by autumn and spring precipitations. The low temperature and high moisture content of the soil

in early spring inhibit the active microbiological processes in it with the result that the soil is severely depleted of inorganic forms of nitrogen.

The best time for dressing in early spring is immediately after thawing of snow, when the fertilizer is spread over the frozen ground. If, dressing is delayed, its effectiveness drastically declines as a result of quick drying of the soil.

Dressing in early spring often involves difficulties in application because of the poor weather conditions. This has prompted experiments in which winter crops were dressed with nitrogen in late autumn with the fertilizer being applied to the frozen soil. The results of such experiments carried out in different parts of the USSR have shown that the grain yield increases due to dressing of winter crops in autumn and spring at equal nitrogen rates are pretty close in magnitude, with the exception of regions with soddy podsolic soils where dressing in autumn produces the poorest results because of partial nitrogen losses due to leaching and washing away. Dressing of winter cereals in late autumn is recommended only on level ground and tenacious soils to avoid such nitrogen losses. Nitrogen fertilizers used for dressing of winter crops should not be spread over the snow cover or over fresh loose snow because they may be blown away with the snow from the fields. Dressing produces good results if performed in spring over a 5- to 7-cm thick layer of packed snow on level ground. In recent years, it has become standard practice to resort to soil dressing of winter crops in spring from a grain drill travelling across plant rows. However, the current literature lacks experimental data supporting the effectiveness of this technique, as compared to the traditional dressing in early spring. Soil dressing with the aid of a grain drill is carried out later than the traditional early spring dressing, that is, when the soil is dry enough not to be crumbled by tractor wheels. The discs of the drill loosen the soil and incorporate the fertilizer into it.

Dressing of winter cereals usually involves ammonium nitrate, ammonium sulphate, and urea. In early spring, a somewhat better effect is attained by using ammonium nitrate, whereas in late autumn the effect is better when ammonium sulphate is used. Application of ammonium nitrate

in spring provides for optimal nitrogen nutrition of winter crops: ammonia nitrogen is retained in the topsoil for a while, and nitrate nitrogen rapidly migrates downwards into the root zone. For urea nitrogen to become available, a certain period of time is necessary for ammonification of urea. This entails nitrogen losses (10% and more) in the form of ammonia.

Experiments indicate that application of $N_{40-60}P_{50-60}$ K_{30-60} increases the yield of winter wheat grain in the major areas of its cultivation from 6 to 10 cent/ha. A greater return from fertilizers is observed in high-rainfall areas.

Different varieties of winter cereals respond differently to improvements in inorganic nutrition, depending on the potentialities of a particular variety and its resistance to lodging. Higher-yielding varieties require more fertilizer.

Proper application of fertilizers not only increases winter crop yields, but also improves the grain quality.

The quality of winter wheat grain is improved by late foliar dressing with nitrogen at the heading, flowering, or early gold ripeness stage. At any one of these stages, the yield remains the same but the protein content in kernels increases by 0.5 to 2 per cent. The gluten content also increases. The best nitrogen fertilizer for foliar dressing is urea. Its spraying concentrations may be brought up to 20, 30, and even 40 per cent. Apart from being a source of nitrogen nutrition, urea is also a physiologically active substance, which markedly intensifies photosynthesis, and, by activating proteolysis in leaves, promotes vigorous efflux of nitrogenous substances from the latter into the ear. There is evidence that a urea solution close to saturation did not burn plants at the flowering stage. Ammonium nitrate causes severe burns at a 2- to 5-per cent concentration of the solution. The optimal rate of nitrogen for foliar dressing is 30 to 45 kg/ha. Spray dressing should be done in a cloudy weather and either early in the morning or in the evening. If spraying is followed by rain, the effectiveness of dressing drops sharply. Experiments carried out at the USSR Research Institute of Fertilizers and Agronomical Soil Science indicate that increased rates of nitrogen fertilizers used for dressing in spring are as effective as the same rates applied twice, early in spring and before flowering. The advantages

of split application of nitrogen for late dressing were observable only on soddy podsolic soils of light texture.

Table 6.17 lists fertilizer rates to be applied to winter crops for attaining the desired yield.

Table 6.17. Fertilizer Rates to Be Applied to Winter Cereals at Medium Mobile Phosphorus and Potassium Contents in the Soil

Soils	Precursor	Esti-mated yield (cent/ha)	Fertilizer rates (manure, in tons, and inorganic fertilizers, in kg of active ingredient per hectare)			
			ma-nure	N	P_2O_5	K_2O
Soddy podsolic moderately loamy and grey forest	Cropped fallow	30-35	30-40	80-100	80-100	60-80
	Ditto	40-45	30-40	120-130	90-120	80-100
Leached cher-nozems	Non-fallow precursor	30-35	—	60-80	60-90	60-80
	Cropped fallow	40-45	20	50-70	50-90	40-50

Treatment of Winter Wheat with Irrigation. The basic procedure here is water-charging irrigation (1000 to 2000 m^3 of water per hectare) performed after deep ploughing. The irrigation water flows via furrows, ditches, and strips. The soil is impregnated with moisture to a depth of one to two and a half metres. Water-charging irrigation increases yields 1.5- to 2-fold. However, such irrigation in a single run does not provide for normal moisture regime in the soil throughout the winter wheat vegetation period. Usually, two to three vegetative runs, each at a rate of 400 to 500 m^3/ha, are allowed.

In the major regions of irrigation farming, winter wheat is grown mainly on chernozems and chestnut soils, where it needs primarily nitrogen and phosphorus fertilizers. The potassium content of these soils is more than adequate.

In the case of irrigated winter wheat, organic fertilizers are usually applied to the preceding crop at a rate of 20 to 50 t/ha. Phosphorus and potassium fertilizers are

ploughed down (prior to water-charging irrigation). A small portion of phosphorus fertilizers (10-15 kg P_2O_5 per ha) is put aside for drilling. Nitrogen fertilizers are in most cases applied in a split manner: about one third of the overall rate is used after water-charging irrigation during cultivation, a sizable portion is used for dressing in early spring, and 30 to 45 kg N per hectare are used for foliar dressing at the heading/flowering stage to improve the quality of grain. Split application of nitrogen fertilizers is most effective on light soils because during irrigation nitrogen is easily leached from them into the underlying layers. Perennial experiments (Ukrainian Research Institute of Irrigation Farming) suggest that on moderately and heavily loamy soils (southern chernozems, chestnut soils) with a deep water table, nitrogen fertilizers used for treatment of winter wheat are equally effective both in presowing application at full rate and in split application.

Irrigated winter wheat must be treated, depending on soil and climatic conditions as well as the farming procedures used, with 60 to 120 kg N, 60 to 90kg P_2O_5, and 0 to 30 kg K_2O per hectare. To attain yields exceeding 50 centners of top quality grain per hectare from high-yielding varieties of winter wheat (Avrora, Kavkaz, Mironovskaya yubileinaya, etc.) grown on Ciscaucasian and southern chernozems, the following fertilizer rates are recommended: $N_{140-200}P_{90-120}$ after grain cereals, $N_{120-180}P_{100-120}K_{40-60}$ after maize for silage, and $N_{80-100}P_{100-120}K_{60-80}$ after alfalfa. To achieve a grain yield of 50 to 60 centners per hectare from irrigated winter wheat in the Lower Volga region where light chestnut soils have medium mobile phosphorus and potassium contents, the recommended rate is $N_{120-150}P_{60-90}K_{40-60}$.

6.7.2 Treatment of Spring Cereals

The major areas of commercial spring cereal grain production include the Volga Region, the Urals, Western and Eastern Siberia, and Kazakhstan, where 95 per cent of all fields occupied by this crop are located. Spring barley and rye are grown practically everywhere.

Oat is less demanding as regards soil fertility and acidity. It thrives on moderately acidic soils and may grow on sandy

loam. Spring wheat and barley require more fertile soils
and a reaction close to neutral or neutral. Their yields drop
sharply on poorly heated heavy soils and soils of light tex-
ture. Spring wheat and barley are more sensitive to the soil
solution concentration than oat. The roots of oat penetrate
to a greater depth, as opposed to spring wheat and barley.
Oat easily takes up nutrients from poorly soluble soil com-
pounds.

The nutrient uptake by spring cereals is most intensive
at the shooting and heading (panicle formation) stages
(Table 6.18).

Table 6.18. Nutrient Uptake by Spring Cereals (% of max.)

Development stage	Spring wheat				Oat		
	Dry matter	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Tillering	12	33	42	37	—	—	—
Shooting	30	65	57	68	—	—	—
Heading (panicle formation)	54	74	73	88	51	36	54
Flowering	77	87	85	100	82	71	100
Milky ripeness	100	100	100	87	90	83	88
Complete ripeness	95	83	97	69	100	100	83

Ten centners of spring cereal grain with straw remove the
following quantities of nutrients (kg): 38 N, 12 P_2O_5, and
25 K_2O—spring wheat; 27 N, 11 P_2O_5, and 24 K_2O—barley;
30 N, 13 P_2O_5, and 29 K_2O—oat.

Hence, to yield unit main product, spring wheat takes
up 1.3 to 1.4 times more nitrogen than oat and barley.

The best precursors of spring cereals in the Non-Black
Earth zone of the European part of the Soviet Union are
lavishly fertilized row crops, perennial grasses on fallow
with or without ploughing, pulses, and fertilized winter
cereals. In the major areas of spring wheat cultivation, where
the amount of precipitation is low, the best precursor is
clean fallow (Siberia, Volga Region, Southern Urals). In
Ciscaucasia, the central chernozem belt, and southern
Ukraine, spring wheat produces high yields after maize, sun-
flower, potatoes, sugar beet, pulses, and perennial grasses.

In the Non-Black Earth zone, on the grey forest soils of the northern part of the forest-steppe zone, on podsolized and leached chernozems, particularly on the leached chernozems of Transuralia and Eastern Siberia, the yield of spring cereals depends largely on nitrogen fertilizers. The nutrient of the second lowest content here is usually phosphorus. Potassium fertilizers are highly effective only on light soils.

On the ordinary and leached chernozems of Western Siberia and ordinary chernozems of the Volga Region with a low moisture content, the yield of spring cereals is increased by application of phosphorus and nitrogen fertilizers. In the arid steppe regions of the south and south-east with their ordinary and southern chernozems as well as chestnut soils, increases in the yield of these crops are almost entirely dependent on phosphorus fertilizers. The effectiveness of nitrogen and potassium fertilizers in these regions is virtually nil.

Spring cereals respond well to application of organic fertilizers, although not as well as winter crops. As a rule, spring cereals are not treated with manure.

If spring wheat is sown on clean fallow or following a lush cover of perennial legumes, nitrogen fertilizers need not be used or, if used, their rates are low. Timely ploughing of fallow occupied by perennial grasses is conducive to accumulation of larger amounts of inorganic nitrogen in the soil, as opposed to ploughing with delay. After pulses, the nitrogen rate is usually cut down by a factor of 1.5 to 2. In all these cases, phosphorus and potassium fertilizers gain in importance. If spring cereals are grown after an insufficiently fertilized precursor that removes large amounts of nutrients when harvested, they need the complete inorganic fertilizer (Table 6.19).

In all parts of the Soviet Union, about 10 kg P_2O_5 per hectare are drilled at seeding of spring cereals in the form of pelletized superphosphate or compound fertilizers.

Preseeding application of phosphorus and potassium fertilizers with ploughdown ensures higher spring cereal grain yields than their incorporation in spring by a cultivator or a disc harrow. This is particularly true in low-rainfall regions. In regions of high and sufficient rainfalls, with soddy podsolic and grey forest soils as well as leached and podso-

Table 6.19. Tentative Fertilizer Rates (kg active ingredient per ha) for Spring Wheat (recommendations of the USSR Research Institute of Fertilizers and Agronomical Soil Science)

Region, soils	N	P_2O_5	K_2O
Central forest-steppe, leached and deep chernozems	40	50	30
Southern and south-eastern steppe, southern chernozems and chestnut soils (with irrigation)	90-120	70	30-40
Ditto, on saline soils	70-90	50	—
Ordinary and Ciscaucasian chernozems (with irrigation)	90-120	70-90	30-40
Steppe, chernozems and chestnut soils without irrigation	—	50	—
Ditto, after late-harvested precursors and rainy autumn	40	50-70	—
All regions with limited fertilizer resources	—	10 (row)	—

lized chernozems, nitrogen fertilizers should be applied in spring. However, ammonia fertilizers, especially liquid ones, may be applied to tenacious soils even in autumn. In low-rainfall regions, nitrogen fertilizers prove to be most effective when incorporated during autumn ploughing, as opposed to spring incorporation by a cultivator.

Spring cereals are not dressed with nitrogen fertilizers in spring, with the possible exception of irrigation farming regions where part of nitrogen (30-40 kg/ha) should be used for dressing in view of the possibility of its being leached out of the root layer.

Moderate application of fertilizers ($N_{40-60}P_{50-60}K_{0-40}$) in various soil and climatic zones of the Soviet Union increases the yield of spring cereal grain by 3 to 8 cent/ha. The smallest yield increases occur in the arid zone, the highest in irrigation farming and high-rainfall regions.

To achieve a spring cereal grain yield of 35 to 40 centners per hectare, it is recommended to apply $N_{100-120}P_{80-100}K_{80-100}$ to soddy podsolic moderately loamy and grey forest soils and $N_{60-70}P_{60-90}K_{50-70}$ to leached chernozems with medium contents of mobile phosphorus and potassium. Irrigated

southern chernozems and chestnut soils must be treated with $N_{90-120}P_{60-90}K_{0-60}$ to attain a grain yield of 40 to 45 centners per hectare. If water-charging irrigation is practised in autumn, nitrogen fertilizers are to be applied afterwards (better in ammonia and amide forms) or in spring, from a cultivator, whereas phosphorus and potassium fertilizers should be ploughed down in autumn.

To improve the grain quality (primarily of spring wheat), spring cereals, just as winter crops, should undergo foliar dressing with urea at the heading/flowering stage.

6.7.3 Treatment of Legumes and Pulses

These crops are capable of taking up atmospheric nitrogen and, to a greater degree than other crops, phosphorus from difficultly available phosphorus compounds of the soil. They have a vertical root penetrating to a depth of one metre and even deeper. Legumes and pulses grow well on tenacious neutral and close to neutral soils and respond well to liming. Only lupine develops normally on acid sandy and sandy loam soils and does not tolerate liming.

Pea and vetch stop taking up nitrogen and potassium by the full flowering stage, whereas the phosphorus uptake is over by their maturation. In lupine and fodder beans, accumulation of nutrients reaches its maximum by the time pods on the main stem become mature. The maximum nutrient uptake by legumes and pulses coincides with the flowering stage. Ten centners of seeds with forage of these crops remove the following average quantities of nutrients (kg):

	N	P_2O_5	K_2O
pea	66	16	20
vetch	65	14	16
lupine	68	19	47
soybean	71	16	18

Under optimal growth conditions, legumes and pulses satisfy about two thirds of their nitrogen requirements from the atmosphere with the aid of nodule bacteria, one third being taken up from the soil. Since nitrogen fixation is strongly inhibited in acid soils, the role of soil-derived nitrogen in ensuring the desired yield becomes predominant. The

best nitrogen-fixing crop is lupine, in contrast to vetch which is at the opposite end of the nitrogen fixation range.

Legumes and pulses are in most cases preceded by winter cereals and row crops.

They respond well to organic fertilizers, although more often than not legumes and pulses are treated by their after-effect. Since these crops can fix atmospheric nitrogen on their own, what they need most is phosphorus and potassium fertilizers. It is widely believed that application of nitrogen fertilizers to legumes and pulses reduces their capacity to fix atmospheric nitrogen, that is, they become ordinary nitrogen consumers just as any other non-leguminous crop. Even in cases where nitrogen fertilizers are recommended, they should be applied at low, "starter" rates (20-30 kg/ha) in order to supply crops with nitrogen at the initial stage of growth when the activity of nodule bacteria is still low. Experiments have shown that the relative amount of nitrogen fixed by leguminous crops from the atmosphere (expressed as percentage of the overall nitrogen removal by crops) decreases with increasing rates of fertilizer nitrogen. This is what made investigators think that application of nitrogen fertilizers inhibits nitrogen fixation by leguminous crops.

The effectiveness of nitrogen fertilizers applied to legumes may depend on soil acidity, phosphorus and potassium nutrition, soil moisture and temperature, seed inoculation, application of various forms of nitrogen and micronutrient fertilizers (primarily molybdenum ones), and other factors. A typical result common to all experiments is that, if the level of soil fertility is not sufficient to satisfy the requirements of legumes for inorganic nitrogen at the early stage of their development (before nodules become fully active) with all other factors being favourable, application of nitrogen fertilizers produces a beneficial effect on their yield, formation of nodules on their roots, and nodule activity. But when the soil contains enough inorganic nitrogen for the early development of legumes (in the case of adequately cultivated soils), nitrogen fertilizers are ineffective as a rule.

The inorganic soil-derived nitrogen requirements of legumes and pulses are directly dependent on the total yield (if it is assumed that they take up from the soil one third

of all nitrogen contained in the plants). Therefore, not every soil can supply legumes and pulses with the necessary amount of inorganic nitrogen to ensure a high yield just by virtue of its fertility.

The greenhouse and field experiments carried out by the department of agricultural chemistry at the Timiryazev Agricultural Academy in Moscow indicate that application of nitrogen fertilizers reduces the relative amount of the nitrogen fixed by legumes and pulses (percentage of its accumulated content in the plant) (Table 6.20).

Table 6.20. Yields and Nitrogen Accumulation in Inoculated Vetch, Pea, and Soybean Plants at Different Uptakes of Inorganic Nitrogen (greenhouse experiments, 6 kg of soil or sand per pot)

| Nitrogen rate (mg/pot) | Yield (g) | | Overall yield removal of nitrogen (mg) | Nitrogen uptake (mg) | | Fixed nitrogen (% of accumulated content in the plant) |
	total (seeds + + straw + roots)	seeds		from fertilizer	from atmosphere	
Vetch (grown on sand)						
100	—	7.5	517	90	394	76
250	—	9.9	737	214	491	66
1000	—	12.1	1088	700	355	32
Pea (grown on soil)						
0	42.8	12.0	670	—	544	81
100	43.3	11.7	672	80	514	77
500	64.1	15.2	1009	400	531	53
1000	69.6	16.6	1245	700	497	40
Soybean (grown on sand)						
50	24.0	11.6	708	—	604	93
168	36.7	16.6	1050	—	839	80
504	58.6	24.2	1755	—	1273	72

Yet, if we consider the absolute nitrogen uptake by legumes and pulses (vetch, pea, soybean, kidney bean) against different nitrogen fertilizer backgrounds, then, at the optimal nitrogen regime (about one half to one third fertilizer

nitrogen of the total yield removal), plants took up from the atmosphere the same and even greater amount of nitrogen, as compared to the case without application of nitrogen fertilizers. This also increased the yield.

Consequently, when plants are adequately supplied with inorganic nitrogen compounds at early stages of their development and favourable conditions are created for symbiotic nitrogen fixation, in the second half of the vegetation period we are dealing with a successful combination of both sources of nitrogen for the plants. Maximum yields of dry matter and grain are obtained, and the overall nitrogen removal rate increases. High nitrogen contents in the soil delay nodule formation. However, their development gains momentum later and becomes even more speedy than against a poor nitrogen background. Low "starter" rates of nitrogen fertilizers produced no effect whatsoever.

Thus, the recently conducted experiments give a better insight into the role of nitrogen fertilizers in treatment of legumes and pulses.

The following approach can be recommended for determining nitrogen fertilizer rates to be applied to legumes and pulses. If the pea seed yield is estimated at 35 centners per hectare and we know that 10 centners of seeds (with forage) remove 60 kg of nitrogen, then the overall nitrogen removal will be 210 kg/ha. About half the nitrogen removed by the useful part of the crop is present in afterharvesting and root residues, that is 105 kg/ha. Hence, the yield from a hectare contains 315 kg N. Under optimal conditions, legumes and pulses take up one third of their nitrogen requirements from the soil and two thirds, by way of nitrogen fixation. In our example, plants take up from the soil about 105 kg/ha of nitrogen (one third of 315 kg). Thus, plants extract from the soil the same amount of nitrogen that is left there in the form of afterharvesting and root residues. It is, therefore, believed that legumes and pulses do not alter the soil nitrogen balance but themselves take care of most of their nitrogen requirements and exert a good aftereffect on other crops through liberation of inorganic nitrogen during decomposition of crop residues. However, not every soil can supply 105 kg of nitrogen per hectare to provide for a yield of 35 cent/ha. This is why a certain quantity of nitrogen

should be added with fertilizers. For instance, if 100 g of chernozem contain 10 mg of easily hydrolyzable nitrogen, the crop may take up, at a nitrogen utilization factor of 20 per cent, 60 kg of nitrogen per hectare. The remaining 45 kg (if no organic fertilizers are used) must be supplied with inorganic fertilizers. At a nitrogen utilization factor of 60 to 70 per cent within the first year, 60 to 75 kg of nitrogen will have to be taken up from a hectare. On soddy podsolic or grey forest soils, this rate will be higher because plants take up less nitrogen from them.

Lupine stands apart among leguminous crops. It does not require nitrogen fertilizers.

The times and techniques of applying inorganic fertilizers to legumes and pulses are the same as in the case of spring cereals. If applied, potassium fertilizers must contain as little chlorine as possible. Used for drilling at seeding is pelletized superphosphate at a rate of 10 kg P_2O_5 per hectare. Treatment of seeds with nitragin of an appropriate group increases their yield by 1.5 to 3 centners per hectare. Legumes and pulses respond well to seed treatment with molybdenum or to foliar dressing with molybdenum fertilizers.

6.7.4 Treatment of Maize

Maize is grown for grain and silage. Grain maize is cultivated in Ciscaucasia, in the south of the Central Black Earth zone, in the Lower Volga region, in Moldavian SSR, Georgian SSR, Azerbaijan SSR, and Central Asian republics.

In low-rainfall regions, the best precursors of maize include winter crops on clean fertilized fallow, legumes, pulses, and maize. Perennial grasses, sunflower, Sudan grass, sugar beet, and 3rd-year maize are not as good because they tend to desiccate the soil considerably. In high-rainfall or irrigation farming regions, maize may be grown on fallow occupied by perennial grasses or ploughed fallow. Maize is very demanding insofar as the nutrient regime of soils is concerned. Soils must be well aerated and have a light texture. Maize also responds positively to liming and produces high yields only if the soil reaction is neutral or close to neu-

tral. The bulk of maize roots (about 60%) occupies the arable
layer to a depth down to 20 cm.

The most of its nutrient requirements are satisfied between
the tasseling and milky ripeness stages (Table 6.21). By the

Table 6.21. Accumulation of Dry Matter and Nutrients by Maize
(% of max.) (data supplied by the Ukrainian Agricultural Academy)

Development stage	Dry matter	N	P_2O_5	K_2O
9 to 10 leaves	1	4	3	4
Tasseling	24	44	33	69
Flowering	35	61	61	79
Milky ripeness	80	89	88	95
Gold ripeness	100	100	94	100
Complete ripeness	94	93	100	82

latter stage, plants accumulate about 90 per cent of the
nutrients they require and 80 per cent of dry matter. The nu-
trient content in the crop is maximum at the gold ripeness
stage. Ten centners of maize grain and forage remove an aver-
age of 34 kg N, 12 kg P_2O_5, and 37 kg K_2O, while the rates
of removal by 100 centners of forage are 25, 12, and 45 kg,
respectively.

Maize is highly responsive to organic fertilizers, especially
in the Non-Black Earth zone. In most cases, high yields of
maize cannot be obtained on soddy podsolic soils without
application of organic fertilizers. On these soils, maize is
usually treated with manure or good compost incorporated
at a rate of 40 to 50 t/ha. In the forest-steppe zone, the ap-
plication rate is 20 to 30 t/ha and in the steppe zone, about
20 t/ha. Experimental results indicate that manuring of
maize at a rate of 20 t/ha on different soils of the forest-
steppe zone increases the grain yield by 4 to 9 cent/ha, the
yield of silage being as high as 90 cent/ha. The best time
to incorporate manure or compost is during deep ploughing
in autumn. The sandy and sandy loam soils of high-rainfall
regions should preferably be manured in spring.

According to the results of experiments carried out by
agrochemical services, treatment of maize with inorganic

fertilizers ($N_{45-60}P_{60}K_{30-60}$) in the major areas of its culti-
vation (on chernozems) increases the grain yield by 6 to
11 cent/ha and the forage yield, by 30 to 120 cent/ha. The
above fertilizer rate ensures a grain yield of 30 to 50 cent/ha
and a forage yield of 250 to 300 cent/ha.

The zonal pattern of effectiveness of various fertilizers
and the influence of the precursor on it are the same for maize
as for the crops discussed earlier.

In low-rainfall regions, nitrogen fertilizers are more effec-
tive when applied during autumn ploughing. In high-rainfall
regions, they must be applied during reploughing or cultiva-
tion in spring. Phosphorus and potassium fertilizers are used
during ploughing in autumn. Only in areas with excessive
moisture content in light soils should potassium fertilizers
be applied in spring. Potassium deficiency in the soil renders
maize prone to lodging. Maize sprouts are extremely sensi-
tive to increased soil solution concentrations. When maize
is sown, it is recommended to apply 5 to 10 kg P_2O_5 per
hectare in the form of pelletized superphosphate at a distance
of 3 to 5 cm aside from the seed and to a depth of 2 to 3 cm
below it. The nitrogen rate in drilling application should
not exceed 2.5 kg/ha. On loamy soils in high-rainfall or ir-
rigation farming regions, taking even a small portion of
nitrogen from the basal fertilizer to be used in dressing (to
say nothing of phosphorus and potassium fertilizers) reduces
yields or does not produce the desired supplemental effect.
Maize should be dressed with nitrogen and potassium
($N_{30-40}K_{30-40}$) only when grown on light soils. Transfer of
part of fertilizers (especially nitrogen and potassium ones)
from basal application to dressing may also be justified
when the annual rate is high. The first dressing is performed
when maize plants reach the height of 15 to 20 cm. In this
case, fertilizers are applied by a side dresser at a distance
of 10 cm on either side of the row, while at later stages of
development, they are placed in the middle between rows.
All types of nitrogen fertilizers produce almost the same
effect on the yield of maize grown on limed soils. Ammonia
and amide forms of nitrogen become superior in some respects
under conditions of irrigation and waterlogging. The best
phosphorus fertilizer is superphosphate. As regards potas-
sium fertilizers, preference should be given to chlorine-

free forms. In the case of moderately cultivated soddy podsolic soils, it is recommended to apply 40 to 50 tons of manure per hectare and $N_{100-120}P_{80-100}K_{0-80}$ to harvest 450 to 500 centners of silage per hectare, while a yield of 700 to 800 centners can be attained if 50 tons of manure and $N_{180-200}P_{120-150}K_{180-200}$ are applied. On leached chernozems, application of 30 to 35 tons of manure per hectare and $N_{70-100}P_{50-80}K_{60-80}$ (after fertilized precursors) allows 60 to 70 centners of grain per hectare to be harvested. In irrigation farming areas, a grain yield of 60 to 80 cent/ha or a forage yield of 600 to 800 cent/ha can be achieved by application of 20 to 30 tons of manure per hectare and $N_{100-180}P_{60-120}K_{0-70}$.

6.7.5 Treatment of Potatoes

The potato is grown mainly in the RSFSR, Ukrainian SSR, and Belorussian SSR. The best soils for its cultivation are chernozems, flood plain soils, reclaimed peat bogs, and also light and moderately loamy soddy podsolic cultivated soils. The optimal soil reaction is weakly acidic. In contrast to most of field crops, the potato is more tolerant to acid soils and higher soil solution concentrations. Its roots are fibrous. Most of them (90-95%) are located in the topsoil.

By the end of the flowering stage, when the haulm takes its final form, potato plants satisfy two thirds to three fourths of their nutrient requirements (Table 6.22).

From the sprouting to early budding stage (May-June), medium late potato varieties accumulate 20 to 27 per cent

Table 6.22. Growth of Haulm and Tubers and Nutrient Accumulation by Potato of the Lorh Variety (% of max.) (data supplied by the Research Institute of Potato Growing)

Month (development stage)	Haulm	Tubers	N	P_2O_5	K_2O
June (early budding stage)	38	6	27	23	20
July (budding and flowering)	100	31	67	75	80
August (max. tuber growth)	94	50	91	85	98
September (ripening)	86	100	100	100	100

of the nutrients they need, the subsequent accumulation rates being 40 to 60 per cent from the budding to late flowering stage (July) and 20 to 33 per cent after flowering. The early potatoes varieties are characterized by the shortest nutrient uptake period—one to one and a half months. Therefore, unfavourable weather conditions affect early potatoes to a greater extent than the late varieties. By harvesting time, potato tubers accumulate nearly 80% N, 90% P_2O_5, and more than 90% K_2O of the total amount of these nutrients in the entire yield. 100 centners of tubers with a respective quantity of haulm remove, depending on soil and climatic conditions, 40-70 kg N, 15-20 kg P_2O_5, and 60-90 kg K_2O. As a rule, early varieties take up less nutrients per unit main product than the late ones, the chief reason being the high haulm-to-tuber ratio in the latter.

The best precursors of potatoes include perennial grasses on ploughed fallow, winter cereals on clean and cropped fertilized fallow, legumes, pulses, annual legume-cereal mixtures, and perennial grasses. Potatoes may also be replanted on the same field.

Excessive liming of the soil causes scab formation on potato tubers, reduces their starch content, and impairs their keeping quality. What liming does in the first place is rendering potassium less readily available to crops, especially to potatoes, flax, and lupine, as a result of enrichment of the soil solution with calcium (or calcium and magnesium). Consequently, the ratio between potassium, on the one hand, and calcium and magnesium, on the other, changes drastically so that the potassium uptake rate goes down. This is why liming must be accompanied by heavy application of potassium fertilizers (their rates must be increased approximately 1.5-fold). In limed soils, the availability of boron is also reduced. To compensate for this reduction, boron fertilizers must be applied (0.7-1 kg B per hectare).

Another reason why liming produces a negative effect on potatoes is upsetting of the optimal ratio between calcium and magnesium uptakes. Therefore, magnesium-containing lime fertilizers are preferable in crop rotations involving potatoes, particularly on light soils. Since in crop rotations potatoes are grown along with other crops responding extremely well to liming, the rotation should be car-

ried out with due account for the biological characteristics of all crops. Typically, in crop rotations with potatoes, lime rates are reduced from overall hydrolytic acidity by one third on medium and heavy soils and by one half on light soils. In crop rotations with a high percentage of potatoes (two and more courses), the lime rates usually do not exceed half the overall rate. In view of the fact that the effect of lime becomes manifest in the second or third year after its application and disappears in the fifth and sixth year at rates amounting to one half of hydrolytic acidity, lime should either be applied directly to potatoes (best of all in spring from a cultivator) or several years in advance, that is, when potatoes will be exposed to a moderate aftereffect of lime. If soils are moderately or highly acidic ($pH_{KCl} \leqslant \leqslant 5.0$), liming of potato fields is a must. The negative effect of lime (even when applied at full rate) on potatoes can be neutralized by heavy application of potassium and placement of lime-magnesium and boron fertilizers.

The potato responds rather well to application of organic fertilizers. Its early varieties take up manure nutrients less vigorously than the late ones because of the shorter vegetation period. The effect of manure on potato yields is most pronounced on soddy podsolic soils of light texture and in high-rainfall regions. The optimal manure rate for potatoes, from the standpoint of crop return from a ton of manure, is up to 40 t/ha on soddy podsolic soils and 20 t/ha on chernozems. Increasing the manure rate lowers the crop return from a ton, although the yield per hectare goes up. As can be inferred from averaged experimental data, application of 20 to 40 tons of manure per hectare in various soil and climatic zones increases the tuber yield by 25 to 60 cent/ha. In most cases, in order to obtain high yields of top quality potatoes, farms of the Non-Black Earth zone apply manure or compost at rates ranging from 50 to 80 t/ha. On the sandy, sandy loam, and slightly loamy soils in high-rainfall regions, manuring in spring is the most effective, while on medium and heavy soils the highest effectiveness is achieved when manure is incorporated during ploughing in autumn. Application of 30 tons of manure per hectare additionally releases 100 to 200 kg CO_2 per day. To yield 300 to 400 cent/ha, one hectare requires 200 to 300 kg CO_2 a

day. Carbon dioxide alone may increase the tuber yield by 30 to 40 per cent. Potatoes extract readily available potassium from manure, virtually without any chlorine, which is also extremely important.

Treatment of potatoes with peat is almost ineffective. Incorporation of peat at a rate of 30 to 40 t/ha seldom increases the tuber yield by more than 10 to 20 per cent. The low effectiveness of peat, when applied alone, stems from the fact that its organic matter decomposes in the soil with great difficulty. Good results are produced by incorporation of green manure into sandy and sandy loam soils. Green manure must be supplemented primarily with phosphorus and potassium fertilizers. Organic fertilizers increase the percentage yield of large tubers.

The most effective on soddy podsolic loamy soils, grey forest soils, podsolized and leached chernozems are nitrogen fertilizers followed by phosphorus and then potassium ones. On sandy and sandy loam soddy podsolic soils, nitrogen fertilizers rank first in effectiveness, potassium fertilizers coming next. On ordinary and deep chernozems, the best fertilizers for potatoes are phosphorus, then nitrogen and, finally, potassium ones, the latter being much less effective. On flood plain and peaty soils, potassium fertilizers are followed by nitrogen and phosphorus ones in the order of their effectiveness. A similar pattern is observed in the case of most other crops. According to the results of experiments in which agrochemical services applied inorganic fertilizers (without manure) at the rate $N_{120}P_{120}K_{90-120}$ to soddy podsolic soils, the potato tuber yield is 195 to 226 cent/ha (the yield increases by 72-85 cent/ha). On light grey and grey forest soils, $N_{120}P_{90-120}K_{120}$ provide for a potato yield of 172-199 cent/ha (62-82 cent/ha increase). On dark grey forest soils as well as podsolized and leached chernozems, a potato yield of 165 to 209 cent/ha (29-67 cent/ha increase) is ensured by $N_{60-120}P_{60-120}K_{90-120}$.

The preplanting application of inorganic fertilizers is as follows. In high-rainfall regions, solid nitrogen fertilizers should be applied during reploughing in spring or ploughing in autumn, whereas liquid ammonia fertilizers may be applied to tenacious soils during autumn ploughing. The best time to apply phosphorus (but not pelletized su-

perphosphate) and potassium (especially chlorine-contain-
ing ones) fertilizers is during autumn ploughing. Only san-
dy and sandy loam soils should be treated with potassium
fertilizers in spring. Pelletized superphosphate and granu-
lated compound fertilizers are most effective when applied
in the row during potato planting. Under different circum-
stances, they should preferably be incorporated during re-
ploughing in spring rather than autumn ploughing. Flood
plain and peaty soils should be treated with inorganic fer-
tilizers only in spring.

When potatoes are planted, inorganic fertilizers are placed
at the rate $N_{20-40}P_{20-40}$ or $N_{20-40}P_{20-40}K_{20-40}$ in the com-
pound form or P_{20-40} in the form of pelletized superphos-
phate. Starter application increases the tuber yield by
25 to 50 centners per hectare.

Putting aside part of nitrogen and potassium fertilizers
$(N_{30-40}K_{30-40})$ for dressing may be justified only in high-
rainfall or irrigation farming regions with sandy and sandy
loam soils where leaching of these fertilizers is possible.

On limed soils, physiologically acidic nitrogen fertilizers
may be preferable within the first few years. Among the
phosphorus fertilizers applied to potatoes only ground phos-
phate rock stands apart. On acid soils ($pH_{KCl} \leqslant 5.0$),
ground phosphate rock may produce the same results as
superphosphate, provided it is applied at twice the latter's
rate in terms of P_2O_5. The best potassium fertilizers for the
potato include potassium sulphate, sulphate of potash-
magnesia, and sulpomag, which are virtually chlorine-free.
These are followed by potassium chloride. Raw potassic salts
are not used for the purpose. On light soils, potash-magnesia
fertilizers are more effective than potassium sulphate.
Although raw potassic salts increase yields somewhat, they
drastically reduce the starch content in potato tubers with
the result that the starch yield per hectare may even be lower
than without application of such fertilizers.

Higher potato yields are obtained by joint application
of organic and inorganic fertilizers, as opposed to their sep-
arate incorporation at equivalent rates in terms of nu-
trients. Manuring of potatoes under various soil and cli-
matic conditions should be supplemented with nitrogen fer-
tilizers added at a rate of 10 to 15 kg N per 10 tons of ma-

nure. This is particularly true for soddy podsolic and grey
forest soils as well as podsolized and leached chernozems,
early potato varieties being more responsive to addition of
nitrogen to manure than the late ones. As a matter of fact,
application of inorganic fertilizers alone may produce high
potato yields, however, the starch content in tubers will
be lower than in the case of organic fertilizers or their ap-
plication together with inorganic fertilizers in appropriate
ratios. Tentative annual fertilizer rates for potatoes grown
on various soils are listed in Table 6.23.

Table 6.23. Fertilizer Rates for Potatoes

Soils	Region	Estimated yield (cent/ha)	Manure (t/ha)	Inorganic fertilizers (kg/ha)		
				N	P_2O_5	K_2O
Soddy podsolic sandy loam	Central	130-150	30-40	100	40-80	60-100
		170-200	30-40	120	60-100	80-120
	Belorussia	150-220	60-70	70-80	30-70	60-100
		220-300	60-70	80-90	40-80	70-130
Soddy podsolic loam	North-West	180-200	30-40	60-90	30-90	40-100
		250-300	40-50	80-120	50-110	60-120
	Central	130-150	30-40	80	40-80	60-80
		200-250	30-40	120	80-100	80-120
	Belorussia	150-220	50-60	60-70	30-80	50-90
		220-300	60-70	70-80	50-90	60-120
Peat-boggy	Belorussia	up to 180	—	—	60-110	80-160
		260-350				
Dark grey, pod-solized and leached cher-nozems	Central chernozem belt, Ukraine	150-200	—	—	80-150	100-200
		200-250	20-30	60-80	40-60	40-90
			20-30	100-130	90-110	120-160

Irrigation of potatoes, especially at the flowering and
intensive tuber formation stages, is a decisive factor of
high yields. Split application of fertilizers during irrigation
is often conducive to higher yields. Here, dressing with
inorganic fertilizers at the rate $N_{20-40}K_{20-40}$ is performed
once or twice. The first dressing is carried out when the plants
reach the height of about 20 cm, and the second, at the bud-
ding stage. The fertilizers are incorporated to a depth of 8
to 12 cm, 12 to 15 cm aside from the plants during the

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first dressing or in the middle between rows during the second.

The highest starch content in potato tubers is usually observed on soils not treated with fertilizers. Organic fertilizers reduce the starch content in tubers but to a much lesser extent than nitrogen ones (at increased rates) and, especially, chlorine-containing potassium fertilizers. Phosphorus renders tubers more starchy.

6.7.6 Treatment of Perennial Grasses in Field, Farm, and Fodder-Grazing Crop Rotations

Leguminous perennial grasses are more demanding as regards soil fertility than cereal ones and thrive on soils close to neutral and neutral. Cereal grasses produce high yields on weakly acidic soils as well. Leguminous grasses are less stable in stands than cereals. Their mortality is due to winter killing, damping, unfavourable soil acidity, as well as phosphorus and potassium deficiency under otherwise favourable conditions, particularly after application of nitrogen fertilizers. The latter is due to the fact that cereals have more developed roots with respect to the rest of the plant, as opposed to leguminous grasses. Therefore, when nitrogen fertilizers whose lack inhibits the development of cereal grasses in the legume-grass mixture are applied, the growth of these grasses is actively promoted, and they take up soil-derived phosphorus and potassium more vigorously owing to the improved absorbing capacity of their roots, whereby phosphorus and potassium nutrition of the leguminous grasses is slowed down. Therefore, in order to preserve legumes in the stand, they must be adequately supplied with phosphorus and potassium, especially when nitrogen fertilizers are used. Phosphorus and potassium fertilizers also enhance winter hardiness and damping resistance of leguminous grasses.

The accumulation of dry matter and nutrients in leguminous perennial grasses is most intensive at the budding and flowering stages. For example, over the flowering stage, clover accumulates about half the dry matter and nutrients it requires. By the earing/flowering stage, top grasses (timothy, meadow fescue, orchard grass, foxtail, etc.) accu-

mulate almost all the nitrogen and potassium they need as well as 80 to 90 per cent of their phosphorus requirements, while bottom cereals accumulate about 70% N, 60% P_2O_5, and 70% K_2O. The average nutrient removal by 10 centners of hay of various perennial grasses is as follows (kg):

	N	P_2O_5	K_2O
red clover	20	6	15
white clover	23	8	13
alfalfa	26	7	15
sainfoin	25	5	13
seradella	25	9	22
timothy	16	7	14

At earlier stages of their development, perennial grasses contain more nutrients per unit dry weight. Therefore, on pastures where grasses are grazed before they are mown, the nutrient removal per unit yield is always greater. This is why the removal of nutrients per ton of hay is always greater after the second cutting, as opposed to the first. On the average, 10 centners of hay from a naturally fertilized meadow remove 15-20 kg N, 4-6 kg P_2O_5, and 15-20 kg K_2O. On properly fertilized pastures, 10 centners of air-dry hay remove 30 kg N, 6-7 kg P_2O_5, and 30 kg K_2O. Ten centners of fresh pasture grass contain an average of 6 kg N, 1.3 P_2O_5, and 6 kg K_2O, whereas 1000 feed units contain 30-35 kg N, 6-7 kg P_2O_5, and 30-35 kg K_2O.

Under optimal cropping conditions, leguminous perennial grasses satisfy two thirds of their nitrogen requirements from the atmosphere and only one third, from the soil. In mixed stands, cereals use up the nitrogen of legumes after the latter die away and after decomposition of their nodules. The number of nodules on the roots of perennial legumes keeps increasing up to the flowering stage whereafter they gradually die off. A nodule stays functional for about six weeks. When clover is cut several times, the onset of the flowering stage is delayed, therefore, nitrogen fixation by nodule bacteria increases. Hence, on pastures the fixation of atmospheric nitrogen by legumes proceeds at a faster rate than on haylands.

Liming produces the best results when lime is applied to the nurse crop or to the crop preceding it, in contrast to surface application to perennial grasses.

In experiments with surface liming of meadows, soil acidity decreased after three and a half years only in the top 0-5 cm layer, while ploughing down of lime before the nurse crop sharply reduced the acidity throughout the arable layer. Liming increases the percentage of legumes and more valuable cereal grasses in the stand. As a result, the protein and calcium contents in the feed increase, too, and pasture grasses become much more eatable. If lime is applied together with ground phosphate rock, the latter is incorporated by a plough with a colter in autumn under the nurse crop, whereas lime is incorporated by a cultivator or a disc harrow.

Organic fertilizer should preferably be ploughed down, when the pasture is established, at a rate of at least 30 to 40 t/ha or in field crop rotation, under the nurse or preceding crop. Surface manuring of perennial grasses involves ammonia nitrogen losses and significantly reduces their eatability, especially during the first and second grazings. Consequently, surface application of organic fertilizers is not recommended. The latter increase the percentage of legumes in the stand, hence, the protein content in the feed.

Manure water may be spread over perennial grasses at a rate of 10 to 20 t/ha, which corresponds to 22-44 kg N and 46-92 kg K_2O. The best time for this treatment is in spring.

Most investigators report that legume-cereal mixtures with 30 and more per cent legumes ensure the same yields as application of 90-180 kg N per hectare of cereal stands, the protein content being higher in the former case. However, highly productive cattle growing requires maximum fodder yields per hectare. To this end, high-yielding irrigated cereal pastures are created with nitrogen supply from inorganic fertilizers. In field crop rotation, legume-cereal mixtures are also treated with nitrogen fertilizers in combination with high phosphorus and potassium rates, which ensures higher yields and a smaller reduction in the percentage of legumes in the stand. Even in the case of an adequately cultivated soddy podsolic soil, additional application of nitrogen against the PK background considerably raises the yields of legume-grass and leguminous mixtures (Table 6.24).

However, at high percentages of legumes in the stand, the effect of low nitrogen rates (less than 30 kg/ha) may be

Table 6.24. Effect of Fertilizers on the Yield of Grasses and Nutrient Removal (data supplied by the USSR Research Institute of Fodder)

Fertilizer	Grass	Hay yield (cent/ha)	Yield removal (kg/ha)		
			N	P_2O_5	K_2O
No fertilizer	Timothy	70.0	75	19	71
	Red clover	48.5	122	20	45
	Timothy+clover	74.7	120	26	76
PK	Timothy	88.6	85	26	121
	Red clover	55.3	138	26	89
	Timothy+clover	82.9	107	33	129
NPK	Timothy	116.5	142	40	170
	Red clover	67.7	169	30	120
	Timothy+clover	107.4	143	40	166

nil. As legumes die away, the nitrogen requirements of grasses grow.

For example, in an experiment conducted at the Institute of Fodder, application of 90 kg/ha of nitrogen to a 1st-year grass mixture in which legumes constituted as much as 50 per cent increased the hay yield by 10 cent/ha; in the 2nd-, 3rd-, and 4th-year stands, as the legumes died away, the yield was increased by 12, 32, and 37 cent/ha, respectively.

To determine the rate of nitrogen fertilizers to be applied to legume-grass stands, the following criterion may be used. If the yield of the 1st-year clover-timothy hay with predominance of clover is estimated at 40 cent/ha, with the nitrogen content in the hay being two per cent, its total quantity in the yield will be 80 kg/ha. The afterharvesting and root residues will contain the same amount of nitrogen, its overall content in the plants being 60 kg/ha.

Under optimal conditions, legumes take up from the soil one third of their total nitrogen content, that is, 53 kg. If a moderately cultivated soddy podsolic soil contains about 5 mg of easily hydrolyzable nitrogen per 100 g of soil, or 150 kg/ha, at a nitrogen utilization factor of 20 per cent, the plants may receive 30 kg of nitrogen from a hectare. The remaining 23 kg of nitrogen must come from inorganic fertilizers. Then, at a utilization factor of 60 per cent,

a hectare must receive with nitrogen fertilizers

$$\frac{23 \times 100}{60} = 40 \ \text{kg N}$$

When the nurse or preceding crop is manured, the nitrogen rate is reduced in view of the residual effect of manure. In the case of the 2nd-year grasses with an increased percentage of timothy, the nitrogen rate must be raised by another 15 to 20 kg, or 1.3- to 1.5-fold.

Some workers believe that the rates of nitrogen fertilizers applied to irrigated legume-grass pastures with a view to preserving legumes in the stand for a longer period of time must range from 50 to 100 kg/ha.

Nitrogen fertilizers account for an especially drastic decrease in the percentage of legumes in the stand when phosphorus and potassium nutrition is insufficient. As a result, the protein yield per hectare is reduced. In cereal stands, nitrogen fertilizers increase the yield of top cereals in the first place. In this case, the raw protein content in the feed goes up. Legumes are more persistent in stands treated with nitrogen not in early spring but early at the shooting stage or, even better, prior to the second cutting. This is due to the more vigorous growth of cereals in spring, as compared to legumes, under conditions of high moisture and low temperatures. Application of nitrogen fertilizers in early spring further accelerates this process, while the development of legumes slows down. Therefore, yields on legume-rich stands can be increased without any marked inhibition of the legumes by applying nitrogen fertilizers to haylands after the first cutting (or after the grasses resume growth), and on pastures this can be done after the first grazing with the aid of phosphorus and potassium fertilizers. Of all nitrogen fertilizers to be broadcast, preference is given to ammonium nitrate as opposed to ammonium sulphate and, especially, urea. Aqua ammonia or anhydrous ammonia can be applied to meadows and pastures not more than once per season by special machines placing these fertilizers to a depth of 12 to 15 cm after cutting the sod with tines spaced 30 cm apart. Application at a closer spacing may damage the sod considerably.

The effect of nitrogen fertilizers is typically restricted

to a single cutting or grazing. Only at high rates (more than 90 kg/ha) they produce a certain aftereffect. Therefore, nitrogen fertilizers are most effective when applied to a cereal pasture with a more even distribution throughout the season at each grazing. This is particularly so in the case of irrigated pastures where the soil moisture content is maintained at a desired level throughout the vegetation period.

In field crop rotation, phosphorus and potassium fertilizers almost double the yield increase if ploughed under the nurse crop (with due account for the requirements of grasses) rather than broadcast over the grasses. When a pasture is established, phosphorus and potassium fertilizers are ploughed down at the rate $P_{100-150}K_{60-150}$. They can also be used for reserve application. However, one must be careful with high potassium rates lest its accumulation in the feed reaches alarming proportions. Grasses are dressed with phosphorus and potassium fertilizers in autumn or in early spring (better in autumn). Phosphorus fertilizers are applied at once, while potassium ones are applied at each cutting or grazing at a rate not exceeding 60 kg K_2O per hectare to avoid excessive accumulation of potassium in the feed. The best phosphorus fertilizer for grass dressing is superphosphate. Reserve application with ploughdown (under the nurse crop) on acid soil should preferably be done with ground phosphate rock. As far as cereal grasses are concerned, the chlorine content in potassium fertilizers is

Table 6.25. Tentative Annual Rates of Inorganic Fertilizers (kg/ha) to Be Applied to Meadows (according to Romashov)

Meadow type	N	P_2O_5	K_2O
Dry and flood plain of high level	30-50	20-30	30-45
Flood plain of medium and low level	30-70	20-30	20-30
Lowland with dark soils	30-50	30-40	40-50
Artificial on drained peat bogs	0-50	30-45	45-90
Meadow-steppe with chernozem-like meadow soils	30-70	30-45	0-20
Mountain-steppe and subalpine	30-50	30-45	20-30

of little significance, legumes being preferably treated with fertilizers containing less chlorine.

The fertilizer rates for various types of hay meadows are presented in Table 6.25.

Irrigated cultivated cereal pastures are treated with higher inorganic fertilizer rates. Cereal pastures on soddy podsolic and grey forest soils (of the same classes in terms of phosphorus and potassium) should be treated with fertilizers at the ratio $N : P_2O_5 : K_2O = 3 : 1 : 1.5$ (e.g. $N_{180-240}P_{60-80}K_{90-120}$). Therewith, application of more than 300 kg N per hectare per season is not always economical, to say nothing of the possible excess of nitrate nitrogen in the feed (more than 0.07% dw). Nitrogen rates usually do not exceed 240 kg/ha. This ensures a yield of 6 to 8 thousand fodder units per season from a hectare.

6.7.7 Treatment of Fibre Flax

Fibre flax is grown mostly in the Non-Black Earth zone. It produces high yields on fertile soddy podsolic moderately and slightly loamy soils. The optimal soil reaction is weakly acidic (pH_{KCl} 5.1-5.5). The requirement that the soil should be fertile stems from the weak absorbing capacity of the root system which consists of a main vertical root and small branch roots, occupying primarily the arable layer. Poorly available soil compounds are taken up by flax with great difficulty. A mobile aluminium content of 2 to 2.5 mg per 100 g of soil produces a toxic effect on fibre flax. Flax is highly sensitive to the soil solution concentration, especially at the seed germination stage. On neutral and calcareous soils, flax suffers from calcium excess and boron deficiency, which makes it prone to bacteriosis. The best precursor of flax is perennial grasses followed, in the order of decreasing importance, by turned fallow, annual legumes and grasses (vetch and pea with oat), potatoes, lupine, and so on. The phosphorus requirements of flax are critical during the period from sprouting to the branching stage, the nitrogen requirements are critical from the branching to budding stage, and the potassium requirements, during the first three weeks of growth (branching stage) as well as at the budding stage when potassium becomes extremely important

for seed formation. By the end of the flowering stage, the uptake of nitrogen and potassium is over, and that of phosphorus amounts to 80-90 per cent. By the onset of the budding stage (approximately 7 weeks after sprouting), fibre flax accumulates 50 to 60 per cent of its nitrogen, 40 to 50 per cent of its phosphorus, and 70 to 75 per cent of its potassium, half of these nutrient amounts being received within the first ten days of rapid growth. From the budding to late flowering stage (a total of three weeks), flax takes up to 40 to 50 per cent of nitrogen, 40 per cent of phosphorus, and 25 to 30 per cent of potassium. The maximum daily average nitrogen uptake is at the flowering stage, while that of phosphorus and potassium is before budding. Ten centres of flax fibre remove an average of 80 kg N, 40 kg P_2O_5, and 70 kg K_2O, the respective rates of removal by 10 centners of straw being 15, 7, and 12 kg.

Liming in crop rotation with flax is based on the same principles as treatment of potatoes. Experiments carried out at the Belorussian Research Institute of Farming on a soddy podsolic slightly loamy soil have shown that the negative aftereffect of liming on flax yields was manifest either when potassium fertilizers were excluded or when they were applied in crop rotation at low rates. In a limed soil, the N : K_2O ratio must not exceed 0.78 at the branching stage and 0.75 at the budding stage. The best ratio at these stages must be in the neighbourhood of 0.5.

Organic fertilizers in crop rotation with flax are applied to cropped fallow, row or winter crops. Flax is not to be treated directly with fresh or slightly decomposed manure because it contains many weed seeds and the field may be heavily infested with weeds. Moreover, since manure cannot be spread over the field in a uniform manner, the flax stand becomes irregular and the plants mature unevenly.

Flax can be treated with well decomposed, fermented poultry manure, or manure water. Manure water should be applied at a rate of 10 to 15 t/ha and poultry manure, at a rate of 1 to 1.5 t/ha; both fertilizers should preferably be applied before seeding. However, application of organic fertilizers to flax preceded by good perennial grasses may cause overnutrition with nitrogen, lodging of the plants, and lowered fibre quality.

Phosphorus and potassium fertilizers should preferably be applied to flax during ploughing in autumn, the best time for application of nitrogen fertilizers being spring reploughing or cultivation of the soil ploughed in autumn. Drilling at seeding involves pelletized superphosphate at a rate of 5 to 10 kg P_2O_5 per hectare. Dressing is performed at the branching stage only with nitrogen fertilizers and only if the plants have not received enough nitrogen before seeding. In the case of soils adequately supplied with nitrogen (after lush clover leas), the $N : P_2O_5 : K_2O$ ratio in the fertilizers must be $1 : 3 : 4$, while in the case of nitrogen-deficient soils this ratio must be $1 : 2 : 2$. Such ratios enhance the quality of flax fibre. The results of 400 experiments carried out by the agrochemical service indicate that treatment of flax (preceded by perennial grasses) with inorganic fertilizers at the rate $N_{40}P_{60}K_{60}$ increases the yield of straw on soddy podsolic soils by 9 to 11 cent/ha (about 2 centners of fibre).

The rates of inorganic fertilizers to be applied to flax, depending on the estimated yield, precursors, and availability of inorganic nutrients in the soil, are given in Table 6.26.

Table 6.26. Rates of Inorganic Fertilizers (kg a.i./ha) to Be Applied to

Estimated fibre yield (cent/ha)	Precursor	Nitrogen rate	P_2O_5 rate at contents low (groups 1-3)
5-7	Inadequately fertilized annual crops, low-yielding grass mixtures	35-50	60-70
	Adequately fertilized annual crops	30-35	50-60
	Good clover lea	20-30	80-90
8-9	Adequately fertilized annual crops	40-45	80-90
	Good clover lea	35-40	90-100
10-12	Adequately fertilized annual crops	50-55	110-120
	Good clover lea	40-45	120-130

In the case of dark waterlogged and limed soils where flax suffers from boron deficiency, it is treated with boron fertilizers (0.5-1 kg B/ha).

Nitrogen overnutrition reduces the strength and yield of long fibre. Potassium and phosphorus fertilizers, on the contrary, improve both. The best nitrogen fertilizer for flax is ammonium sulphate followed by ammonium nitrate and urea. Ammonium sulphate increases the number of individual fibres in the stalk more effectively than any other nitrogen fertilizer. When phosphorus fertilizers are applied properly, their different forms produce the same effect on fibre yield and quality. The best potassium fertilizers for flax include potassium sulphate and sulphate of potash-magnesia. Chlorine-containing potassium fertilizers exert a somewhat negative effect on the yield and quality of flax fibres (especially raw salts). The negative effect of the chlorine ion on flax is amplified by the calcium ion.

6.7.8 Treatment of Sunflower

Oil-bearing sunflower is cultivated on chernozems and chestnut soils, and when it is grown for silage, its fields extend into regions with soddy podsolic soils. The optimal

Fibre Flax Grown on Soddy Podsolic Soils of Belorussia

the following mobile phosphorus in the soil		K_2O rates at the following mobile potassium contents in the soil		
medium (groups 4-5)	high (group 6)	low (groups 1-2)	medium (groups 3-4)	high (groups 5-6)
40-50	20	90-100	50-60	20-30
30-40	row	80-90	40-50	20-30
50-60	20-30	90-100	70-80	40-50
60-70	40-50	90-100	80-90	50-60
70-80	50-60	110-120	100-110	60-70
80-90	60-70	100-120	100-110	70-80
90-100	70-80	130-150	110-120	90-100

soil acidity for this crop is close to neutral, and the soil texture must be moderately loamy. Sunflower has long roots penetrating the soil to a depth of 4 to 5 m and extending horizontally 1 to 1.2 m from the stem. Sunflower is most often sown after winter and spring cereals as well as pulses (with the exception of kidney bean). To protect sunflower against diseases, it should be sown on the same crop rotation field not earlier than after eight years. Sunflower vigorously takes up soil-derived phosphorus and potassium and thrives under the aftereffect of the organic, phosphorus, and potassium fertilizers applied earlier. It can intensively take up potassium from poorly soluble soil compounds and phosphorus from tricalcium phosphate. Freshly precipitated aluminium and even iron phosphates are more or less readily available to this crop. Sunflower is a potassium loving crop. Ten centners of sunflower seeds with a respective amount of by-products remove an average of 60 kg N, 26 kg P_2O_5, and 180 kg K_2O, while 100 centners of sunflower forage remove 30 kg N, 10 kg P_2O_5, and 45 kg K_2O. As reported by the Agricultural Institute in Saratov, sunflower accumulates about 65 per cent of its dry matter during the period between head formation and formation of achenes, that is, over a 1.5-month interval. During the same period, it takes up 65% N, 70% P_2O_5, and only 35% K_2O. The potassium uptake is substantial (40%) from achene formation to ripening.

Manuring of sunflower grown on chernozems and chestnut soils at a rate of 20 t/ha increases the seed yield by two to five centners per hectare depending on moisture conditions. When sunflower is grown on soddy podsolic and grey forest soils for silage, application of 20 to 30 tons of manure per hectare increases the forage yield by 50 to 100 cent/ha.

In areas where oil-bearing sunflower is grown, potassium fertilizers are often ineffective because of the high content of mobile potassium in chernozems and chestnut soils. This is why nitrogen and phosphorus fertilizers are used there, while in the arid zone only phosphorus fertilizers are applied at rates ranging from 40 to 60 kg P_2O_5 per hectare. Field experiments have shown that inorganic fertilizers applied at the rate $N_{40-60}P_{45-60}K_{0-40}$ to chernozems and chestnut soils increase the yield of seeds by three to five

centners per hectare to 14-25 cent/ha. On soddy podsolic and grey forest soils with a medium content of mobile phosphorus and potassium, a sunflower forage yield of 250 to 350 cent/ha can be obtained by applying inorganic fertilizers at the rate $N_{90-120}P_{60-90}K_{90-120}$ or, together with 30 to 40 tons of organic fertilizers, $N_{60-90}P_{30-50}K_{60-90}$. Inorganic fertilizers are usually applied twice, i.e. basally and in rows at seeding. The row fertilizer is P_{15-30} in the form of pelletized superphosphate or $N_{10-15}P_{15-30}$ in compound form The row fertilizer increases the yield of seeds by 1.5 to 2.5 cent/ha. The dressing rate is $N_{30-40}K_{30-40}$. In the case of irrigation, the first dressing is performed at the stage of two to three pairs of leaves, and the second, early at the head formation stage. The fertilizers are incorporated by a side dresser to a depth of 10 to 12 cm, 12 to 15 cm aside from a row during the first dressing and in the middle between two rows during the second. Irrigated chernozems and chestnut soils with a medium content of mobile phosphorus and potassium must be treated with $N_{120-150}P_{120-150}K_{180-250}$ and $N_{150-200}P_{120-150}K_{180-250}$, respectively, to yield 40 centners of sunflower seeds per hectare.

6.7.9 Treatment of Sugar Beet

In low-rainfall regions, the best precursors of sugar beet are lavishly fertilized winter crops following black fallow. In high-rainfall regions, sugar beet is grown mainly after winter crops following perennial grasses or pulses.

High yields of sugar beet call for fertile cultivated soils of neutral and even weakly alkaline reaction. This crop is characterized by high salt endurance. On lined, calcareous and neutral soils, sugar beet requires boron fertilizers (0.7-1 kg B/ha). Boron deficiency causes heart rot and hollowness.

The rootage of a mature sugar beet plant includes a thick tap root and thin branch roots extending 40 to 50 cm away from the centre. The root system may penetrate to a depth of two to two and a half metres. 100 centners of roots (with a respective quantity of tops) remove an average of 50-60 kg N, 15-20 kg P_2O_5, and 60-90 kg K_2O. In northern regions, the nutrient removal rate is higher than in western

and southern ones. This can be explained by a greater per-
centage of tops in the yields produced in northern regions.
The peak of nutrient uptake by sugar beet falls on the period
preceding August (about 70% of the maximum content).
By that time, more than 60 per cent of dry matter in the
tops and one third in the roots are accumulated. The remain-
ing 30 per cent of nutrients are taken up within the next
one and a half months when the root yield increase reaches
its peak. The critical period of sugar beet nutrition coincides
with the early top formation stage (June 15 to July 1).
During these two weeks, the plants satisfy 25 to 30 per cent
of their nutrient requirements.

The fertilizer system for sugar beet comprises application
of organic, phosphorus, and potassium fertilizers during
autumn ploughing or spring reploughing. Application of
phosphorus and potassium fertilizers from a cultivator is
not rational, especially in dry years. In low-rainfall regions,
nitrogen fertilizers should also be applied starting in autumn.
Putting even a little nitrogen aside for dressing is not advis-
able, to say nothing of phosphorus and potassium fertilizers.
In irrigation farming areas, two to three dressings (20-40 kg
NK/ha each) may be performed with the fertilizers being
applied before vegetative irrigations. Drilling at seeding
involves 15-20 kg P_2O_5 per hectare in the form of pelletized
superphosphate or in compound form with appropriate addi-
tions of nitrogen and potassium. Systematic heavy applica-
tion of a basal fertilizer (100 and more kg NPK per hectare
at a time) eliminates the need in drilling.

Manure may be applied either directly to sugar beet or
to the precursors (winter crops and cropped fallow). The
average manuring rate is 20 to 30 kg/ha. The manure must
be half-decomposed. Fresh straw manure causes desiccation
of the soil and heavy infestation with weeds. Application
of 20 tons of half-decomposed manure per hectare to sugar
beet grown in various regions increases the root yield by 20
to 120 cent/ha, which is slightly lower than the yield increase
provided by inorganic fertilizers at the rate $N_{60}P_{60}K_{60}$.
The highest yield increases due to manure are attained in
irrigation farming (80-120 cent/ha) and high-rainfall (30-
50 cent/ha) regions.

The experimental data supplied by the agrochemical ser-

vice indicate that application of inorganic fertilizers at the rate $N_{120}P_{90-120}K_{90-120}$ in the major sugar beet growing regions of the USSR increases the root yield by 70 to 140 cent/ha. The zonal pattern of effectiveness of nitrogen, phosphorus, and potassium fertilizers applied to sugar beet remains the same as in the case of the crops discussed above. The best nitrogen fertilizer for sugar beet is, in most cases, sodium nitrate. Aqua ammonia produces almost the same effect as ammonium nitrate. At a more acidic soil reaction, some preference for basal application is given to precipitate and Thomas slag over superphosphate, while at neutral and weakly alkaline reactions, it is the other way round. We can speak of the effectiveness of ground phosphate rock only in the context of acid soils ($pH_{KCl} \leqslant 5$). However, sugar beet grows poorly on such soils. Therefore, ground phosphate rock is not important as fertilizer for this crop.

The preferable potassium fertilizer is sylvinite followed, in order of decreasing effectiveness, by 40% potassic salt, kainite and schoenite, potassium chloride, and potassium sulphate, that is, we are dealing with a sequence opposite to that involved in the treatment of other crops. Raw salts contain sodium which plays an important role for sugar beet. As regards chlorine, it does not produce any negative effect on it. After winter crops following perennial grasses, high-quality sugar beet roots are obtained on leached chernozem and grey forest soils treated with inorganic fertilizers at the ratio $N : P_2O_5 : K_2O = 1 : 1 : 1.5$ or $1 : 1 : 2$.

Joint application of manure and inorganic fertilizers increases the yield of roots and sugar from a hectare, although it reduces the sugar content per unit weight to some extent. When manure is applied together with inorganic fertilizers to grey forest soils, leached and podsolized chernozems, it must be supplemented primarily with nitrogen fertilizers. On deep, slightly leached, and ordinary chernozems, nitrogen fertilizers applied together with manure become less effective. Depending on soil and climatic conditions, to harvest 300 to 350 centners of sugar beet from a hectare in the major areas of its cultivation (Table 6.27) requires manure at a rate of 20 to 30 t/ha (applied to sugar beet or its precursor) and $N_{100-170}P_{130-180}K_{100-170}$.

Table 6.27. Fertilizer Rates for Sugar Beet (at a yield of
300-350 cent/ha)

Region	Soils	Manure (t/ha)	Inorganic fertilizers (kg a.i./ha)		
			N	P_2O_5	K_2O
Central, Volga-Vyatka, central chernozem belt, Volga	Grey forest, podsolized, leached, and typical chernozems	20-30	130-170	130-150	140-170
	Ordinary chernozems	20-30	100-120	140-160	110-150
Ciscaucasia	Ciscaucasian leached chernozems	20-30	140-150	140-150	130-140
	Ciscaucasian deep and low-humus chernozems, chestnut soils	20-30	100-130	140-180	120-130
Altay Territory	Leached and ordinary chernozems	20-30	100-140	140-150	100-150
Belorussia	Soddy-podsolic	70-80	100-120	50-110	80-170
	Peat-boggy	—	—	70-140	80-200

Note: After a leguminous precursor, nitrogen rates are reduced by about 30 kg

Irrigated ordinary (southern) chernozems and chestnut soils must be treated with manure at a rate of 20-30 t/ha (applied to the preceding crop or sugar beet) and $N_{90-150} \times P_{40-90} K_{40-60}$ to attain a sugar beet root yield of 500 to 600 cent/ha. In irrigation farming regions, phosphorus and potassium fertilizers are incorporated into the soil during ploughing in autumn, while nitrogen fertilizers are used during preplanting cultivation or for dressing. In the case of washing and water-charging irrigation, nitrogen fertilizers are not applied during autumn ploughing. Otherwise, one third of the nitrogen rate can be applied in autumn, preferably in ammonia or amide form.

6.8 Preparation of Fertilizer System for Crop Rotation

The basic documents to be used in the preparation of a fertilizer system must include the management and production plan of a collective or state farm outlining the program of

its development (yield increases, crop rotations, supply of inorganic fertilizers, cattle stock growth, productivity of animal raising, etc.), the soil map, agrochemical charts, the statistics of yields over the past five years as well as organic and inorganic fertilizer rates, and the record of the cropping history. One must assess the management and technical potential of the farm insofar as timely fertilizing is concerned and envisage strict supervision of fertilizer application to the farm fields.

The fertilizer system is prepared in the following sequence.

(1) Crop rotation or alternation on every field is specified for each year. Crop yields in individual rotation cycles and fields are defined and the yields by the year crop rotation are implemented. All this must be correlated with the overall farm estimates.

(2) The areas of acid soils to be limed are defined for each crop rotation cycle. The average contents of mobile phosphorus and potassium of each crop rotation field as well as the average for the entire crop rotation area are determined (the class of soil in terms of each of these nutrients). If the farm has acid soils, liming rates and schedule in crop rotation are defined with due account for the biological characteristics of the rotating crops. Also defined is the schedule of application of ground phosphate rock alone or in combination with manure and other inorganic fertilizers. In liming, particular attention should be given to application of boron fertilizers (especially to potatoes and flax).

(3) The availability of manure and other organic fertilizers is estimated. Their total amount is distributed among individual crop rotation cycles, the rates of their application to individual crops are established, and layouts of their piles on individual fields are drawn for better planning of their spreading.

(4) Inorganic fertilizers are distributed among individual rotating crops depending on the estimated yields or the amount of fertilizers supplied to a hectare of crop rotation fields.

(a) *Distribution of Inorganic Fertilizers in Crop Rotation Depending on the Estimated Yields of Individual Crops.* The rates of inorganic fertilizers in crop rotation, taking into consideration the estimated yields, are determined using the

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above-described methods with due account for the weighted average supply (class) of the soil of the entire crop rotation area with mobile phosphorus and potassium, the precursor, and the fertilizer aftereffect.

If the nutrient requirements of a particular crop are satisfied by organic fertilizers and the aftereffect of the fertilizers applied earlier, a starter (row) fertilizer is planned as well as application of small amounts of nitrogen to winter crops during dressing in spring (primarily in the Non-Black Earth zone).

After inorganic fertilizers have been distributed (in kg a.i./ha) among rotating crops, the resulting fertilizer system is verified by drawing up the nutrient balance per crop rotation cycle and defining the nutrient utilization factors over the same period.

The standard nutrient balances per crop rotation cycle for soddy podsolic and grey forest soils, as a function of the average supply of the crop rotation soils with mobile phosphorus and potassium, were presented above (see Table 6.11).

Phosphorus and potassium losses from the root layer are virtually nil but for a small amount of potassium lost from sandy and sandy loam soils. It may be assumed that the losses of soil-derived nitrogen due to leaching of nitrates and denitrification are compensated by the nitrogen supplied into the soil with precipitations, from seeds, and by the activity of free-living nitrogen-fixing bacteria. Therefore, in drawing up the nitrogen balance in crop rotation, entered in the debit side is only the yield removal of this nutrient, except for cases involving leguminous crops, while the credit side includes the supply of nitrogen with organic and inorganic fertilizers as well as the nitrogen of perennial legumes, left by them in the soil in compensation for the yield removal.

Enrichment of the soil with nitrogen from perennial grasses is determined as follows. For example, at clover/timothy hay yields of 45 cent/ha during the first year and the same yields during the second year, the rate of nitrogen removal by hay over the two years is 180 kg/ha (hay contains about 2% nitrogen or 20 kg nitrogen per ton). A ton of hay leaves in the soil 10 to 15 kg of nitrogen per hectare in the form of afterharvesting and root residues. In this

Table 6.28. Fertilizer Rates and Nutrient Balance in Crop Rotation Soil: soddy podsolic, moderately loamy; contents averaged over crop rotation: P_2O_5—5-10 mg/100 g of soil (class III) and K_2O—8-12 mg/100 g of soil (class III) (Kirsanov's classification); manure contains 0.4% N, 0.2% P_2O_5 and 0.5% K_2O

Crop alternation	Removal by 10 centners of main product + by-products (kg)			Estimated yield (cent/ha)	Nutrient removal by estimated yield (kg/ha)			Fertilizer rate to attain the estimated yield (manure in t/ha; fertilizers in kg a.i./ha)				Yield without fertilizer (cent/ha)	Yield increase (cent/ha)	Nutrient removal per yield increment (kg/ha)		
	N	P_2O_5	K_2O		N	P_2O_5	K_2O	manure	N	P_2O_5	K_2O			N	P_2O_5	K_2O
Barley + grasses	27	11	24	30	81	33	72		50	120	200	10	20	54	22	48
1st-year grasses	13*	6	20	45	—	27	90		40	—	—	20	25	32	15	50
2nd-year grasses	15*	6	20	45	—	27	90		50	150	150	20	25	37	15	50
Winter wheat	35	12	26	40	140	48	104		100	150	150	10	30	105	36	78
Potato	6	2	9	250	150	50	225		60	20	20	60	190	114	38	170
Maize for silage	2.5	1.2	4.5	400	100	48	180	60	30	60	120	100	300	75	36	135
Crop rotation total					471	233	761	60	330	350	490			417	162	531

Nutrients applied with 60 t of manure (kg): N = 240, P_2O_5 = 120, K_2O = 300

Nitrogen accumulated in the soil from perennial grasses (kg): 30

Total nutrients received by the soil (kg): N = 600, P_2O_5 = 470, K_2O = 790

Nutrient balance (% of removal): 127, 202, 104
Difference between nutrient supply and removal (kg): +129, +237, +29
or per hectare (kg): +21.5, +39.6, +4.8

$$UF_N = \frac{417 \times 100}{570} = 73\%$$

$$UF_{P_2O_5} = \frac{162 \times 100}{470} = 34.5\%$$

$$UF_{K_2O} = \frac{531 \times 100}{790} = 67\%$$

A crop rotation hectare is supplied with 7.8 centners of inorganic (standard) fertilizers and 10 tons of organic fertilizers.

Note. *-Only soil and fertilizer nitrogen removal.
UF—fertilizer nutrient utilization factor.

particular case, afterharvesting and root residues over a hect-
are contain about 135 kg of nitrogen (15N $\times$ 9 = 135),
the harvested hay and the residues containing a total of
about 315 kg of nitrogen. Under the best circumstances, one
third of the total nitrogen requirements, or 105 kg, are satis-
fied from the soil. Hence, the rate of soil enrichment with
nitrogen from perennial grasses is 30 kg/ha (135 — 105 =
= 30). Under conditions unfavourable for nitrogen fixation,
this rate will be smaller.

In the case of pulses and annual leguminous grasses, the
nitrogen balance is assumed to be zero. When annual legumes
and grasses (vetch with oat, pea with oat) are grown with
heavy predominance of oat, the nitrogen balance is negative.

According to Table 6.28, the nutrient balance per crop
rotation cycle (% of yield removal) is as follows: $\frac{600 \times 100}{471} =$
= 127% in terms of nitrogen, $\frac{470 \times 100}{233} = 202\%$ in terms
of phosphorus, and $\frac{790 \times 100}{761} = 104\%$ in terms of potassium.

The factor of fertilizer nutrient utilization per crop rota-
tion cycle is determined by the ratio between the amount
of the nutrient removed by yield increment and its amount
received by the soil from organic and inorganic fertilizers

Table 6.29. Average Yields of Some Crops (cent/ha) on Various Soils
different economic regions) (agrochemical service data for the period

Soil	Winter wheat	Winter rye	Spring wheat	Barley and oat
Soddy podsolic sandy loam		10-12		
Soddy podsolic loam	14-18	12-14	10-15	11-17
Grey forest	17-25	13-15	13-18	17-25
Podsolized chernozem	17-25		16-19	
Leached chernozem	19-33	12-20	15-21	15-21
Typical chernozem	19-23		18-19	16-24
Ordinary chernozem	19-23		14-16	20-26
Southern chernozem	23		12-15	17-18
Chestnut	15-23		10-15	13
Sierozem				

Note. In actual farming, the yields of grain crops are lower by about 25%

and is expressed as percentage. The following fertilizer (both organic and inorganic) nutrient utilization factors are typical for a crop rotation cycle: nitrogen, 60 to 70 per cent; phosphorus, 35 to 40 per cent; and potassium, 65 to 75 per cent. By yield increment is here meant the difference between the estimated yield and the yield without fertilizers. The latter yield is based on the data supplied by the agro-chemical service (Table 6.29) or determined from mobile phosphorus (in tenacious soils) and mobile potassium (in light soils); it can also be derived from the approximate content of easily hydrolyzable nitrogen in the soil (see p. 177).

The balance of nutrients and the factors of their utilization by crops within a rotation cycle give every reason, in the above example (Table 6.28), to expect the desired yields, provided the weather conditions are right. The nutrient balance gives a rough idea of the possible changes in the contents of mobile phosphorus and potassium in the soil by the end of the crop rotation cycle.

The availability of inorganic fertilizers for crop rotation is determined in the following manner: the amount of the nutrient received by the soil from inorganic fertilizers per rotation cycle is divided by the number of fields (six in

Without Fertilizer (the averages vary by groups of experiments in from 1965 to 1974)

Grain maize	Maize for silage	Potato	Sugar beet	Fibre flax (straw)	Sunflower for seeds	Seed cotton
38-40 37 33 27	250 220-250 170-215 140-230	110-140 110-120 130-140 130-140	260-290 180-310 200 190-260	21-27	16-22 14-17 14-17 13-18 10	18-26

and those of row crops, by 30 to 40%.

the example illustrated by Table 6.28, the area of each field being assumed to equal a hectare) and converted into standard fertilizer. The $N : P_2O_5 : K_2O$ ratio in inorganic fertilizer is 1 : 1 : 1.4. The soil receives from manure and inorganic fertilizers, per crop rotation cycle, $N_{570}P_{470}K_{790}$, that is, the $N : P_2O_5 : K_2O$ ratio is 1.2 : 1 : 1.

The overall inorganic fertilizer rate determined for each crop is subdivided into basal, starter, and dressing rates (Table 6.30).

Table 6.30. Fertilizer System for Crop Rotation (manure in t/ha and inorganic fertilizers in kg a.i./ha)

Crop alternation	Basal application				Starter application			Press-ing with N
	manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O	
Barley + grasses		40	110	190	10	10	10	
1st-year grasses								40
2nd-year grasses								50
Winter wheat		30	140	140	10	10	10	60
Potato	60	40			20	20	20	
Maize for silage		30	50	120		10		

The above standard nutrient balances for crop rotation on soddy podsolic and grey forest soils (Table 6.11) are, in theory, applicable to other soils as well. However, in farming practice, considerable departures from them are tolerated, primarily because at the present stage inorganic fertilizers are used where they are highly effective in the first place. Therefore, in low-rainfall regions, for example, where the effectiveness of fertilizers is low and they are used in small amounts, the nutrient balance becomes negative (mainly in terms of nitrogen and potassium).

When a fertilizer system for crop rotation is drawn up, the nutrient balances in the major soil types are typically as follows (% of removal):

	N	P_2O_5	K_2O
Soddy podsolic and grey forest soils (high-rainfall regions)	120-130	170-250	85-130
Leached, typical, and ordinary chernozems (regions with unreliable rainfalls)	65-85	100-180	30-75
Ordinary and southern chernozems, chestnut soils (regions with unreliable rainfall)	30-55	60-90	10-35
Southern chenozems and chestnut soils (irrigation farming regions)	80-100	130-170	30-75

When the fertilizer rates are determined from the estimated crop yields in order to render fertilizers as effective as possible (without taking into account the subsequent changes in soil fertility), the crop rotation nutrient balance becomes dependent on the yield increase level (Table 6.31).

Table 6.31. Standard Nutrient Balance in Crop Rotation When Fertilizer Rates Are Determined from Yield Increases (at different levels of yield increase due to fertilizers)

Yield increase per crop rotation cycle due to fertilizers (% of yield without fertilizers)	Nutrient balance per crop rotation cycle (% of yield removal)		
	N	P_2O_5	K_2O
30	35-40	60-65	30-35
50	50-55	85-95	45-50
70	65-70	105-120	60-65
100	80-85	125-145	70-75
150	95-100	150-170	85-90
200	105-110	170-190	95-100
300	120-125	190-215	105-115
400	125-130	200-230	115-125
500	135-140	210-240	120-130

The tabulated data can be applied to various types of soils with medium contents of mobile nutrients. As can be inferred from the table, the phosphorus balance becomes positive as soon as the yield increase due to fertilizer exceeds the control yield (without fertilizers) by 70 per cent, the nitrogen and potassium balances becoming twice as high at the same time.

In preparing Table 6.31, the factors of nutrient utilization from organic and inorganic fertilizers by the rotating crops were assumed equal to 60-65 per cent for nitrogen, 35-40 per cent for phosphorus, and 65-70 per cent for potassium. The balance of each nutrient in this particular case can be calculated using the following formula:

$$B = \frac{I \times 100}{U \times (100 + I)} \times 100$$

where B is the nutrient balance per crop rotation cycle (% of yield removal), U is the factor of nutrient utilization per crop rotation cycle (%), and I is the relative yield increment or relative nutrient removal increment with respect to fertilizer application per crop rotation cycle (% of yield without fertilizers), 100 (in the denominator) stands for yield without fertilizers or yield removal of the nutrient. It is assumed by convention that, when yields in crop rotation increase by, say, 30 and 50 per cent due to fertilizers, the nutrient removal rate also increases in proportion, that is, also by 30 and 50 per cent.

The above method of verifying the fertilizer system for crop rotation with reference to the nutrient balance allows agronomists to estimate changes in soil fertility in the course of time. Furthermore, by controlling the nutrient balance one can equalize the fertility of different fields.

(b) *Distribution of Inorganic Fertilizers in Crop Rotation Depending on the Amount of Fertilizers Supplied to a Hectare of Crop Rotation Fields.* This approach is justified only when the farm receives small quantities of inorganic fertilizers (3-5 cent/ha in terms of standard fertilizer), that is, when they are applied primarily to the leading crops.

First of all, all rotating crops are treated with row phosphorus fertilizer. Then, nitrogen fertilizers must be allocated for spring dressing of winter crops and for enhancing the effectiveness of manure or compost in the year of their application. Usually, 10 to 15 kg of inorganic fertilizer nitrogen are used for every 10 tons of manure or compost incorporated into the soil (a larger amount is used for row crops). Nitrogen fertilizers should also be applied to plots treated in the preceding years with high rates of phosphorus and potassium fertilizers, so as to maximize their aftereffect. The preseeding

(basal) fertilizer is applied only to the most important farm
crops with due account for the nutrient ratio for individual
crops (Table 6.32) as well as for the aftereffect of the pre-

Table 6.32. Inorganic Fertilizer Nutrient Ratios for Various Farm Crops
(on unfertilized soil and the same soil class in terms of mobile
phosphorus and potassium contents)

Crop	$N : P_2O_5 : K_2O$ ratio
Cereals	$1 : 1 : 1$
Pulses	$0 : 2 : 1$ or $1 : 2 : 1$
Perennial legumes and legume-grass mixtures	$0 : 1 : 1$ or $0.7 : 1 : 1$
Vetch with oat	$0.7 : 1 : 1$ or $1 : 1 : 1$
Pea with oat grown for green fodder and silage	$0.5 : 1 : 1.5$ or $0.7 : 1 : 1.5$
Flax (after poor grasses, row and grain crops)	$1 : 2 : 2$
Flax (after good clover)	$1 : 3 : 4$
Potato, fodder root crops	$1 : 1 : 1.5$
Maize and sunflower for silage	$1 : 1 : 1.5$
Cabbage, carrot, beet, tomato, cucumber	$1 : 1 : 1.5$

viously applied fertilizers, the effect of the afterharvesting
and root residues of legumes, soil type (on chernozems, the
percentage of nitrogen is reduced by 30 to 50), and the con-
tent of mobile nutrients in the soil.

For instance, soddy podsolic soil is characterized by a me-
dium content of phosphorus and potassium. If grain crops
grown on such a soil are treated with inorganic fertilizers
at the rate $N_{60}P_{60}K_{60}$, with a utilization factor of 50 per
cent for nitrogen, 20 per cent for phosphorus, and 50 per
cent for potassium, they will take up 30 kg N, 12 kg P_2O_5,
and 30 kg K_2O from the fertilizers during the first year. This
will increase the grain yield by about 10 centners, each nu-
trient contributing equally to the increase. However, if grain
crops are sown the next year on the same soil, it would be
wrong to apply inorganic fertilizers at the same rate. The
appropriate procedure would be to increase the nitrogen
nutrition in order to make a fuller use of the aftereffect of
phosphorus and potassium fertilizers.

Table 6.33. Fertilizer System for Nine-Course Field Crop Rotation on Soddy Podsolic Moderately Loamy Soil with Medium Mobile Phosphorus (class III) and Potassium (class III) Contents

Crop alternation	Estimated yield (cent/ha)	Fertilizer rates				Including							
		peat manure compost	N	P₂O₅	K₂O	basal				starter*			dressing
						peat-manure compost	N	P₂O₅	K₂O	N	P₂O₅	K₂O	N
Vetch + oat (hay)	45	20	40	40	60	20	30	30	50	10	10	10	
Winter wheat	30		80	80	80		30	70	70	10	10	10	40
Potato	250	40	100	40	90	40	60		50	40	40	40	
Barley + grasses	30		40	150	180		40	140	180		10		
1st-year grasses (hay)	45		30										30
2nd-year grasses (hay)	45		50										50
Winter wheat	30		50	100	100			90	90	10	10	10	40
Maize for silage	350	30	80	50	100	30	80	40	100		10		
Oat	30		60	10	60		50		50	10	10	10	

* Primarily in the form of compound fertilizers.

Note. Peat-manure compost is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 10 t of organic fertilizers and N₅₉P₅₂K₇₄. The N : P₂O₅ : K₂O ratio in inorganic fertilizers is 1.1 : 1 : 1.4. An approximate nutrient balance per crop rotation cycle (% of removal) is: 135% N, 195% P₂O₅, 110% K₂O.

Table 6.34. Fertilizer System for Eight-Course Farm Crop Rotation on Soddy Podsolic Moderately Loamy Soil with Medium Mobile Phosphorus (class III) and Increased Mobile Potassium (class III) Contents

Field No.	Crop alternation	Estimated yield (cent/ha)	Basal fertilizer				Starter fertilizer			Dressing
			peat-manure compost	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N
1	1/2 pea/oat (fodder)	250	40							
	1/2 vetch/oat (hay)	50								
2	Winter rye (fodder) + 1/2 pea/oat (fodder)	200			30	60	10	10	10	30
	1/2 maize for silage	200		50	50	100		10	10	
3	Fodder beet	600	60	210	120	240	10	10		
4	Maize for silage	500		80	50	150		10		
5	1/2 barley + grasses, 1/2 oat + grasses	30		70	150	200		10		
6	1st-year perennial grasses (hay)	50								30
7	2nd-year perennial grasses (hay)	50								50
8	Winter rye (grain)	35			80	120	10	10	10	50

Note. Peat-manure compost is given in tons, inorganic fertilizers, in kg a.i./ha. A hectare of crop rotation fields receives 12.5 t of organic fertilizers and $N_{75}P_{69}K_{112}$. The $N : P_2O_5 : K_2O$ ratio in inorganic fertilizers is 1.1 : 1 : 1.6. An approximate nutrient balance per crop rotation cycle (% of removal) is: 135% N, 190% P_2O_5, 100% K_2O.

(5) An annual fertilizer application plan is drawn up taking into account the specific features of each crop rotation field. The overall scheme of organic and inorganic fertilizer application in crop rotation, based on averaged agrochemical soil indicators (phosphorus and potassium contents), forms the basis for drafting the annual fertilizing plan by individual crop rotation fields, that is, the overall rate of inorganic fertilizer nutrients to be applied to a particular crop is adjusted according to the soil class of each field (or plot), in terms of mobile phosphorus and potassium supply.

If the difference between nutrient supply to the soil of an individual field and the supply of crop rotation soils with phosphorus or potassium is one or two classes, the rates of phosphorus or potassium fertilizers in the annual plan are increased or decreased by 20 to 30 and 40 to 60 per cent, respectively, while the nitrogen rate is increased or decreased by 10 to 20 per cent. In this case, the nitrogen fertilizer

Table 6.35. Fertilizer System for Seven-Course Field Cereal-Flax-Grass Rotation on Soddy Podsolic Moderately Loamy Soil with Medium Mobile Phosphorus (class III) and Potassium (class III) Contents

Crop alternation	Estimated yield (cent/ha)	Basal fertilizer				Starter fertilizer			Dressing
		peat-manure compost	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N
Pea/oat (silage)	250	30	60	40	60		10		
Winter wheat + grasses	30		30	130	250		10		30
1st-year perennial grasses (hay)	40								
2nd-year perennial grasses (hay)	40								30
Flax (fibre)	7		20	80	90		10		
Potato	250	40	70	30	100	20	20	20	
Oat	35		60	40	60		10		

Note. Peat-manure compost is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 10 t of organic fertilizers and $N_{43}P_{54}K_{83}$. The N : P_2O_5 : K_2O ratio in inorganic fertilizers is 0.8 : 1 : 1.5. An approximate nutrient balance per crop rotation cycle (% of removal) is: 130% N, 200% P_2O_5, 115% K_2O.

rate is adjusted according to the soil class in terms of phosphorus.

If crop rotation is not yet implemented or some fields have extremely low fertility, it would be more expedient to prepare the fertilizer system for each field on a year by year basis with due account for its specific features. Sometimes, in order to considerably raise the fertility of fields, they must be treated with organic fertilizers not once per crop rotation cycle (as specified in the overall scheme of the fertilizer system), but several times and at higher rates, which will also leave an imprint on the fertilizer system for such a field.

(6) In drafting the annual plan, validation is made of the fertilizers to be applied to individual crops with indication of their biological characteristics, nutrient uptake behaviour, response to soil acidity, the specific aspects of treating them with organic and various forms of inorganic fertilizers, and the effect of fertilizers on the crop quality.

Table 6.36. Fertilizer System for Ten-Course Field Crop Rotation on Leached Chernozem with Low Content of Mobile Phosphorus (class II) and Medium Content of Mobile Potassium (class III)

Crop alternation	Estimated yield (cent/ha)	Basal fertilizer				Starter fertilizer	Dressing
		manure	N	P_2O_5	K_2O	P_2O_5	N
Oat + perennial grasses	25		40	110	120	10	
1st-year perennial grasses	35						
Winter wheat	30			60	60	10	30
Maize for silage	350	20	40	40	40	10	
Barley	30		30	30	40	10	
Pea (seeds)	25		40	60	40	10	
Winter wheat	30			40	50	10	30
Maize for silage	350	20	50	40	40	10	
Vetch/oat (hay)	35			30	40	10	
Winter wheat	30			60	50	10	10

Note. Manure is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 4 t of organic fertilizers and $N_{30}P_{56}K_{48}$. The N : P_2O_5 : K_2O ratio in inorganic fertilizers is 0.54 : 1 : 0.86. An approximate nutrient balance per crop rotation cycle (% of removal) is: 75% N, 193% P_2O_5, 77% K_2O.

Table 6.37. Fertilizer System for Nine-Course Cereal-Beet Rotation on Leached Chernozem with Medium Mobile Phosphorus and Potassium Contents

Crop alternation	Basal fertilizer				Starter fertilizer			Dressing
	manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N
Barley+clover		50	70	100		10		
Clover								
Winter wheat		30	120	130		10		70
Sugar beet	30	220	110	170	10	10	10	
Maize for silage		70	50	130		10		
Pea (seeds)		50	30			10		
Winter wheat		40	110	120	10	10	10	50
Sugar beet	30	220	100	170	10	10	10	
Grain maize		60		40		10		

Note. Manure is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 6.7 t of organic fertilizers and $N_{96}P_{74}K_{99}$ at an N : P_2O_5 : K_2O ratio of 1.3 : 1 : 1.3. The approximate yields are: grain, 45 cent/ha; sugar beet, 500 cent/ha; maize forage, 500 cent/ha; hay, 50 cent/ha. An approximate nutrient balance (% of removal) is: 85% N, 145% P_2O_5, 75% K_2O.

Table 6.38. Fertilizer System for Ten-Course Field Crop Rotation on Ordinary Chernozem in the Steppe Zone (data supplied by the Donetsk Regional Experimental Station)

Crop alternation	Yield (cent/ha)		Fertilizer rates				Including row fertilizer (P_2O_5)
	without fertilizers	with fertilizers	manure	N	P_2O_5	K_2O	
Black fallow	—	—					
Winter wheat	25.7	31.8	10		45	15	7.5
Winter wheat	13.6	19.1		30	45	30	7.5
Grain maize	20.4	23.8		15	45		7.5
Barley	16.8	21.8			7.5		7.5
Black fallow	—	—					
Winter wheat	20.4	25.8	10	15	45	30	7.5
Grain maize	29.7	33.4		15	45	30	7.5
Sunflower (seeds)	19.1	23.0		15	45	30	7.5
Pea, barley	16.4	19.9					

Note. Manure is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 2 t of organic fertilizers and $N_9P_{27}K_{14}$. The N : P_2O_5 : K_2O ratio in inorganic fertilizers is 0.33 : 1 : 0.52. The nutrient balance per crop rotation cycle (% of removal) is: 29% N, 143% P_2O_5, 33% K_2O.

Table 6.39. Fertilizer System for Nine-Course Field Crop Rotation on Dark Chestnut Soil with Low Mobile Phosphorus Content (class II) and High Mobile Potassium Content (class V) in Dry Steppe of the Lower Volga Region

Crop alternation	Basal fertilizer				Row fertil-izer	Dressing
	manure	N	P_2O_5	K_2O	P_2O_5	N
Black fallow	20		40-60			
Winter wheat					10	30*
Spring wheat					10	
Spring wheat		30			10	
Grain maize		30-40	30-40	30	10	
Spring wheat					10	
Annual grasses millet					10	
Spring wheat		30-40	40-50	30-40	10	
Barley					10	

* The dressing is done with urea at the heading/flowering stage [to in-crease the protein content in kernels.

Note. Manure is given in tons, inorganic fertilizers, in kg a.i./ha. One hectare of crop rotation fields receives 2.2 t of organic fertilizers and $N_{13-16}P_{21-26}K_{7-8}$. The $N : P_2O_5 : K_2O$ ratio in inorganic fertilizers is 0.65 : 1 : 0.3.

The application times and techniques are also specified here.

(7) Derived from the annual plan is the fertilizer application schedule, the availability of inorganic fertilizers is de-fined with a breakdown according to their forms, and the requirements for their storage facilities are determined.

(8) The requirements for farm machinery are determined with a time schedule for application and incorporation of organic and inorganic fertilizers.

(9) The estimated yield increase is used to calculate the economic efficiency of the developed fertilizer system for crop rotation, with allowance for the crop return and the expenses involved in harvesting of the additional yield resulting from the increase due to fertilizer and in fertilizer application.

(10) For the developed fertilizer system to be successful, additional agrotechnical and organizational activities are

planned, such as assignment of mechanized fertilizer application teams, recommendations for use of micronutrient fertilizers, and the like.

Given below are schemes of fertilizer systems for field and fodder crop rotations (Tables 6.33 through 6.39).

6.9 Fertilizer System for Special Crop Rotations

6.9.1 Fertilizer System for Crop Rotations Involving Rice

Rice is grown in the irrigation farming areas of Central Asia, Transcaucasia, Ciscaucasia, the Primorsky (Maritime) Territory, southern Ukraine, and the lower reaches of the Volga, Don, Dnieper, Bug, and Danube rivers.

Rice is a thermophilic and light-demanding crop with very high water requirements. It should preferably be cultivated on soils whose reaction is close to neutral and neutral. Acceptable yields of this crop are possible on weakly acidic and weakly alkaline soils. The rice-producing zone encompasses a great diversity of soils, from podsolic in the Primorsky Territory to desert soils. Most of rice paddies occupy saline soils. Paddy soils must have a high content of organic matter and moderately to heavily loamy or clayey texture, that is, with good water-retaining properties. Light soils are not suitable for rice. When flooded, the soil becomes a site of reduction processes due to its anaerobiosis with the result that it contains mobile compounds of humic substances (of the fulvic acid type) as well as iron, sulphur, phosphorus, and manganese. At the same time, oxidation processes occur in the microzone of the rice rhizosphere, involving aerobic microflora (nitrifiers, azotobacters, sulphoficators). Oxygen is translocated from leaves into roots and the rhizosphere by virtue of the peculiar biology of rice plants. Oxygen disappears from the soil a day after flooding, and reduction processes become intensive in it already after five days. The resulting lower oxides are extremely harmful to plants. However, they are oxidized in the aerobic root microzone, partially precipitate, and become available and harmless nutrients for rice. The nutrient uptake by rice plants is most strongly inhibited by the hydrogen sulphide

forming in the soil. A major role in neutralizing hydrogen sulphide is played by ferrous iron, whereby water-insoluble ferrous sulphide harmless to plants is formed. The inorganic nitrogen compounds predominant in the soil during vegetation of rice include primarily ammonia nitrogen. As regards nitrate nitrogen, it virtually disappears five to eight days after flooding. The nitrates present in the soil before flooding are leached out and also undergo denitrification. Yet nitrates are always present in the aerobic root microzone, which is why their losses are inevitable. In view of this, application of nitrification inhibitors together with nitrogen fertilizers (about 1 % of the total fertilizer weight) deserves closer attention. In paddy soils, blue-green algae may accumulate as much as 20 to 200 kg of nitrogen per hectare and about one ton of organic matter. Rice bay flooding enhances the availability of phosphates in the soil. Young rice plants start suffering from salt concentrations when the content of chlorides exceeds 0.1 per cent and that of sulphates, 0.2 per cent; adult plants tolerate salt concentrations up to 0.7 per cent.

Rice has fibrous, horizontally branched roots with a low absorbing capacity, 80 per cent of them occupying the top 4- to 6-cm soil layer. From the sprouting to tillering stage (3 to 4 leaves), rice is especially sensitive to phosphorus and nitrogen deficiency. It also demands nitrogen at the tillering and shooting stages, lack of nitrogen in this period inhibiting the development of the panicle and lowering its kernel content. The time interval between tillering and flowering is when the nutrient uptake is at its peak, especially that of phosphorus (Table 6.40).

Table 6.40. Nutrient Uptake by Rice Over Its Vegetation Period ($\%$ of max.) (data supplied by the Uzbek Experimental Rice Station)

Development stage	N	P_2O_5	K_2O
Sprouting/tillering	26	2	20
Flowering	99	100	100
Ripening	100	100	100

Ten centners of rice grain (paddy) with a respective quantity of straw remove an average of 22 kg N, 10 kg P_2O_5, and 30 kg K_2O.

The typical precursors of rice include alfalfa, clover, legumed fallow, and rice, alfalfa and clover being the best and rice, the worst. Perennial grasses in crop rotation with rice are ploughed up in the third year. If rice follows perennial grasses, the nitrogen fertilizer rates are cut almost in half, while those of phosphorus and sometimes potassium fertilizers are increased. The farther in time rice is sown after perennial grasses, the more nitrogen is applied to it. Three to four years of continuous rice cultivation or sowing it after another cereal precursor calls for an increase in the nitrogen fertilizer rate by about one third of the average rate.

The organic fertilizers applied to rice include manure, compost, and green manure. Manure and composts should preferably be incorporated into the soil during autumn ploughing at a rate of 20 to 40 t/ha. Such a rate increases the grain yield of rice by 20 to 35 per cent. Peas, winter and spring vetch, soybean, mung bean, and other crops are grown on green fallow for use as green manure. The green manure must be supplemented primarily with phosphorus fertilizers.

Nitrogen fertilizers in rice-producing areas are of paramount importance. Their rates are determined by the precursor. They are applied in a split manner, that is, before sowing and for dressing. The basal application is at one half to two thirds of the overall nitrogen fertilizer rate with the fertilizers being incorporated to a depth of 8 to 10 cm by a cultivator or disc harrow shortly before sowing (to minimize the nitrification of ammonia nitrogen). In the case of heavier soils, the percentage of nitrogen in the basal fertilizer increases. The dressing is done once (to good sprouts or at the tillering stage) or two to three times (to good sprouts, at the tillering stage, and, to raise the grain quality, at the panicle formation and flowering stages) with equal nitrogen dosages. Dressing on lighter soils is more frequent. Preference is often given to dressing twice: at the stage of formation of two to three leaves and at the tillering stage. The dressing rate is usually 30 to 40 kg of nitrogen per hectare. Before dressing, the flooding of paddies is stopped (water must be fully imbibed by the soil), then resumed two

to four days after dressing. The fertilizers are sprayed from an airplane or a helicopter. Urea should be used for late foliar dressing at the rate N_{30-40}, which is done at the tillering/flowering stage. The best nitrogen fertilizers for rice are ammonium sulphate, urea, and ammonium chloride, that is, ammonia and amide forms. Ammonium nitrate and especially nitrate forms of fertilizers are less effective because of the heavy losses of nitrate nitrogen due to leaching and denitrification. When ammonium chloride is applied, chlorine is soon leached from the soil and does not produce any negative effect on the plants, therefore, this fertilizer is as effective as ammonium sulphate. The factor of fertilizer nitrogen utilization by rice is typically 20 to 50 per cent.

Phosphorus fertilizers in rice-producing areas are most effective when used together with nitrogen ones. However, there is no consensus as to the times of their application. In some cases, phosphorus is recommended to be applied at full rate before sowing during ploughing in autumn or presowing cultivation, in others, the application must be split with about one half to two thirds being applied before sowing and the rest being used for dressing at the stage of good sprouts or at the tillering stage. In some experiments, rice yields were increased by a row fertilizer at the rate P_{10} in the form of pelletized superphosphate. The best phosphorus fertilizer for rice is superphosphate. The phosphorus fertilizer rates depend on the mobile phosphorus content in the soil. According to Stolypin, for example, the rice paddies of Uzbekistan with a low mobile phosphorus content should be treated with 60-90 kg P_2O_5 per hectare, those with a medium content should be treated with about 30 kg P_2O_5, and paddies with a high mobile phosphorus content need not be treated with phosphorus fertilizers. The phosphorus fertilizer rates applied to rice typically range from 60 to 120 kg P_2O_5 per hectare.

Soils in rice-producing areas are usually well supplied with mobile potassium, which is why potassium fertilizers are not effective. They increase yields mainly on old and flood plain soils. Potassium fertilizer rates usually range from 50 to 100 kg K_2O per hectare. Rice can be treated with all forms of these fertilizers, the most widely used ones being potassium chloride and potassic salt. Paddies are treated

before sowing either at full potassium fertilizer rate or
with 50 to 70 per cent, the rest being applied at the tillering
or shooting stage. Putting part of potassium fertilizers aside
for dressing is most advisable on less heavy loamy soils where
they may be leached from the root layer.

Field experiments in the major rice-producing areas indi-
cate that application of inorganic fertilizers after different
precursors at the rate $N_{60-180}P_{60-150}K_{0-100}$ increases the
grain yield by 15 to 25 cent/ha, its total amount being 47
to 65 cent/ha.

Inorganic fertilizer rates for rice grown in the Lower Volga
Region and Ciscaucasia are given in Table 6.41.

Table 6.41. Fertilizer Rates for Rice (kg a.i./ha) to Attain Grain Yields
of 50 to 60 Centners Per Hectare

Precursors of rice	Lower Volga			Ciscaucasia		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Perennial grasses	90	60	—	60	60	—
Ploughed fallow	120	50	60	120	90	50
Fertilized cropped fallow	120	30	—	90	90	—
Old paddies	150	60	60	150-180	90-120	60

The effectiveness of inorganic fertilizers depends on rice
varieties. For example, the variety Uzros 7-13 responds bet-
ter to them than Uzros 59.

Joint application of organic and inorganic fertilizers pro-
duces the best effect on rice, in which case the rates of the
latter are lowered by a factor of 1.5 to 2. Proper combination
of both fertilizers not only ensures high yields, but also
improves the quality of rice kernels. The fertilizer systems
for crop rotation with rice, increasing the grain yield by 50
to 60 cent/ha, are given in Tables 6.42 and 6.43.

By resorting to advanced cropping practices and by using
an appropriate fertilizer system, a rice farm in the Krasno-
dar Territory harvested 67.5 centners of rice grain per hect-
are in 1975. At this farm, an average rice treatment rate is
$N_{150-180}P_{100-140}K_{40}$.

Table 6.42. Fertilizer System for Seven-Course Crop Rotation with Rice in Ciscaucasia and Southern Ukraine (manure in tons, inorganic fertilizers in kg a.i./ha)

Crop alternation	Basal fertilizer				Dressing		
	manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Alfalfa			120-150	60			
Alfalfa							
Rice		30-45	40-70	60-80	20	20	
Rice		60-80	60-90	40-60	20-30	20	20
Cropped fallow (maize+winter pea)		30	30	60	50	30	60
Rice	20-40	60-90	60-90	40-60	30	30	20
Rice		90-100	30-60	60	30-50	30	20

Note. One hectare of crop rotation fields receives an average of 3.0 to 5.7 t of manure and $N_{67}P_{77}K_{66}$, the $N : P_2O_5 : K_2O$ ratio in the latter being 0.87 : 1 : 0.86

Table 6.43. Fertilizer System for Seven-Course Crop Rotation with Rice in Central Asia (manure in tons, inorganic fertilizers in kg a.i./ha)

Crop alternation	Basal fertilizer				Dressing		
	manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Alfalfa			120	60			
Alfalfa							
Rice			30-50		30-40		(1)
					50-60	30-40	(2)
Rice			30		40-50		(1)
					60-70	30	(2)
Cropped fallow (Central Asian sorghum + winter vetch)		50	90	100	100		
Rice	30-40	40	30	30	40-50		(1)
					40-60	0-30	30 (2)
		40-50	30	30	50-60		(1)
					60-70	0-30	30 (2)

Note. The first dressing (1) is done at the good sprout stage and the second (2), at the tillering stage. One hectare of crop rotation fields receives an average of 4.3 to 5.7 t of manure and $N_{93}P_{62}K_{40}$, the $N : P_2O_5 : K_2O$ ratio in the latter being 1.5 : 1 : 0.65.

6.9.2 Fertilizer System for Crop Rotations Involving Cotton

Cotton is grown primarily on sierozems, sierozem-meadow, and meadow-boggy soils containing 1-4% humus, high amounts of mobile potassium, and much lower quantities of mobile phosphorus. Soils with a shallow water table are not suitable for the purpose. The texture of soils in cotton-growing areas ranges from moderately to heavily loamy, and also clayey and sandy loam soils. Most of these soils are prone to salinization and require washing irrigation. The optimal soil reaction for the development of cotton plants is neutral and weakly alkaline. Cotton has well developed vertical roots penetrating to a depth of 1.5 to 2 m. The bulk of roots occupies the 0-60 cm soil layer. Starting with the flowering stage, cotton takes up 80 to 90 per cent of the maximum amount of the nutrients it requires (Table 6.44). However,

Table 6.44. Dry Matter and Nutrient Accumulation in Cotton (% of max.)

Development stage	Dry matter	N	P_2O_5	K_2O
Budding	2	4	3	3
Early flowering	12	18	13	18
Full flowering	30	50	36	55
Ripening	100	100	100	100

the critical period of phosphorus and nitrogen uptake is the interim between sprouting of cotton seeds and formation of four to five leaves. Potassium is of little significance during the period in question. Nitrogen deficiency immediately after sprouting causes formation of many lateral (monopodial) branches, which lowers the yields of raw cotton. Potassium plays the most important role during boll formation and ripening. Depending on the cotton variety, its vegetation period may be anywhere from 100 to 170 days long, the nutrient removal by a ton of raw cotton being 30-60 kg N, 10-20 kg P_2O_5, and 30-60 kg K_2O. In view of the wider difference between the vegetative and reproductive parts of the late-ripening varieties, the nutrient removal by them is greater per ton than by the early varieties.

In the crop rotations of cotton farms, cotton accounts for 66 to 80 per cent of the farming area. The predominant crop rotations are cotton-alfalfa ones in which alfalfa is grown in two to three courses and cotton, in five to nine. The 2nd- or 3rd-year alfalfa is the best precursor of cotton and ensures its high yields for the next three to four years. Alfalfa enriches the soil with nitrogen and organic matter but, at the same time, phosphorus and potassium fertilizers grow in importance for cotton. Alfalfa grown in the cotton-producing areas is treated with phosphorus fertilizers in the first place.

Organic fertilizers are usually applied to cotton in the fourth or fifth year of its cultivation after alfalfa. Half-decomposed manure at a rate of 20 to 40 t/ha is ploughed down in autumn or in spring if the fields undergo washing irrigation. Green manure can also be used. To this end, intermediate crops are grown in the crop rotation, which produce more than 30 tons of green material over the autumn-spring period.

Immediately after alfalfa with or without ploughing, nitrogen rates applied to cotton are usually 2 to 1.3 times lower than in the third or fourth year of its cultivation after alfalfa. The longer the time period between alfalfa and cotton in crop rotation, the more nitrogen is required, organic fertilizers become necessary, the phosphorus fertilizer rates increase and those of potassium fertilizers decrease. The rate of nitrogen for treatment of cotton may be as high as 300 kg/ha. The nitrogen fertilizer rates for cotton are corrected depending on the total content of nitrate and ammonia nitrogen in the soil in the following manner:

$N (NO_3 + NH_4)$ (in mg/100 g of soil)	Correction factor to the recommended nitrogen rate
0.5-1.5	1.25
1.6-3.0	1.00
3.1-4.5	0.75
4.6-5.0	0.50

Nitrogen fertilizers are applied to cotton several times (before seeding, at seeding, and two to three dressings), which improves the conditions of nitrogen nutrition of the plants. At annual nitrogen rates of about 100 kg/ha, it should preferably be used for dressing. At higher nitrogen rates, 20 to 30 per cent (30-70 kg/ha) are usually applied before

seeding, while the rest is divided into almost equal portions (20-40% or 30-75 kg/ha) to be used in two or three dressings: at the stage of two to four leaves (30-50 kg N/ha), at the early budding stage (30-75 kg N/ha), and at an early flowering stage (30-75 kg N/ha). At seeding, 10 to 20 kg N per hectare are placed. The last dressing must be over no later than ten days after the onset of the flowering stage. Otherwise, the ripening of cotton plants is delayed, the overall yield and prefrost harvesting of raw cotton are reduced, the yield of unripe bolls increases, and the fibre quality is lowered. On soils with a shallow water table, drained soils, and saline soils requiring washing irrigation in autumn and in winter, nitrogen fertilizers are used for basal application by a cultivator in spring. In other cases, when no washing irrigation is performed, ammonia and amide fertilizers can be applied during autumn ploughing. The amount of nitrogen to be applied before seeding also depends on the soil type. On light and drained soils, the postseeding nitrogen fertilizer application rate increases with respect to other applications.

Phosphorus fertilizers should be used during ploughing in autumn. Shallow placement of these fertilizers, for example by a cultivator in spring, lowers drastically their effectiveness. Some phosphorus losses are possible only due to washing irrigation and on properly drained soils. In these cases, it is better to plough them down in spring or incorporate into deeper soil layers by a cultivator. Most of the annual rate of phosphorus fertilizers is applied before seeding, 20-40 kg P_2O_5 per hectare being applied at seeding in the row. The phosphorus fertilizer rate must be dependent on the mobile phosphorus content in the soil. According to the results of field experiments carried out by zonal agrochemical laboratories of the Uzbek SSR, the optimal P_2O_5 rate is 150 kg/ha at a low content of mobile phosphorus in the soil, 100 kg/ha at a medium mobile phosphorus content, and 50 kg/ha at an increased or high phosphorus content, the nitrogen rate being 200 kg/ha to attain a raw cotton yield of 35 cent/ha. Superphosphate is the best phosphorus fertilizer for cotton. Among the excellent nutrients is also the phosphorus of compound fertilizers in which it is present primarily as a water-soluble fraction.

The soils of cotton-producing regions are usually well supplied with potassium. However, after many years of their cultivation, a need arises to use potassium fertilizers. At low annual rates of the latter (up to 50 kg K_2O per hectare), they should better be used for dressing at the early budding stage. In the case of drained soils, the full rate of potassium fertilizers is applied in the course of vegetation (but not later than the budding stage) in order to avoid unnecessary potassium losses due to leaching. When there is no washing irrigation, half the annual rate of potassium fertilizers is applied during ploughing in autumn, and the rest is used for dressing at a rate of 30 to 50 kg K_2O per hectare per dressing. Dressing with potassium must be over by the onset of the budding stage. Cotton is dressed with potassium once or twice. Experimental data indicate that on soils with a very low or low mobile potassium content, up to 100 kg K_2O per hectare increase cotton yields, whereas at a higher potassium content in the soil, K_2O rates in excess of 50 kg/ha fail to produce any effect. The best potassium fertilizers for cotton, especially those used for dressing, are chlorine-free forms.

Cotton should be treated with compound fertilizers at the rate $N_{10-20}P_{20-40}$. If they are not available, pelletized superphosphate alone will do the job. The fertilizers should be incorporated to a depth of 10 to 12 cm, 5 to 7 cm aside from seeds.

Throughout the vegetation period, cotton is dressed two to three times with the fertilizers being applied before irrigation. Before the budding stage, they are incorporated by a side dresser to a depth of at least 10 cm and at a distance of 15 to 20 cm from the plants, while at a later stage the fertilizers are incorporated to a depth of 4 to 18 cm below the bottom of the irrigation furrow, in the middle between rows.

The effectiveness of treatment largely depends on the cotton irrigation schedule. Waterings are distributed among three stages of cotton development: before flowering, flowering/vigorous boll formation, and ripening. The watering frequency is the highest (2-5) at the second stage. Throughout the vegetation period, cotton is watered two to twelve times at an irrigation rate of 2 to 8.5 thousand cubic metres per hectare. It has been experimentally established that at an

optimal irrigation schedule without fertilizers it takes about 300 m³ of water per hectare of cotton field, this amount being cut down almost 2.5 times (120-130 m³) if the fertilizer rate and irrigation schedule are optimized. According to the Tashkent affiliate of the Central Institute of Agrochemical Service (TsINAO), the best nitrogen fertilizer for use in the first and second dressings is urea as a relatively slow-acting form, while for the flowering stage ammonium nitrate is best. Application of urea alone at all the three stages reduced the yield of raw cotton by 2 cent/ha. This can be explained by the more persistent effect of urea nitrogen on plants after flowering, which delays the ripening of bolls.

Application of inorganic fertilizers in the major cotton-growing regions at the rate $N_{170-180}P_{110-120}K_{30-50}$ increased the yield of raw cotton by 12 to 19 cent/ha (the yield without fertilizers was 18-26 cent/ha).

The recommended rates of inorganic fertilizers to attain desired cotton yields on the basic types of soils are listed in Table 6.45. Depending on the time interval between alfalfa

Table 6.45. Annual Inorganic Fertilizer Rates to Attain Desired Cotton Yields on Various Soils (kg a.i./ha)

Estimated yield of raw cotton (cent/ha)	N	P_2O_5	K_2O
Sierozems			
20-25	160-200	110-140	50-80
25-30	200-230	140-160	60-100
30-35	220-270	160-190	70-120
35-40	260-300	180-210	80-120
40-45	290-330	200-230	90-120
Light meadow soils			
20-25	150-170	110-150	60-80
25-30	160-220	150-180	80-100
30-35	220-270	170-220	80-120
35-40	250-300	190-240	80-120
40-45	280-330	220-270	80-120
Dark meadow and swampy meadow soils			
20-25	140-170	110-140	40-80
25-30	170-200	140-160	50-100
30-35	200-230	160-190	60-110
35-40	220-250	180-200	70-120
40-45	240-280	190-220	80-130

and cotton in crop rotation, the rates of nitrogen fertilizers are adjusted using the following correction factors: 0.4-0.5 for the first year after alfalfa, 0.6-0.75 for the second year, 0.8-1.0 for the third year, and 1.0 for the fourth and fifth years. The rates of phosphorus and potassium fertilizers are adjusted depending on the mobile phosphorus and potassium contents in the soil, the correction factors being 1.25 at low contents, 1.0 at medium contents, 0.75 at increased contents, 0.5 at high contents, and 0.2-0.25 at very high contents.

Table 6.46 summarizes the recommendations given by the Tashkent affiliate of TsINAO for the Uzbek SSR as regards

Table 6.46. Inorganic Fertilizer Rates (kg a.i./ha) to Attain Raw Cotton Yields of 30 to 35 Centners per Hectare on Typical Sierozems of the Uzbek SSR (data supplied by the Tashkent affiliate of TsINAO)

Nutrient content in the soil	Annual fertilizer rate	Including					
		plough-down	pre-seeding culti-vation	seed-ing	stage of two leaves	bud-ding stage	flow-ering stage
Nitrogen fertilizers (N)							
Medium	250	—	70	20	50	60	50
Phosphorus fertilizers (P_2O_5)							
Low	225	135	--	30	--	—	60
Medium	175	105	—	30	-	---	40
Moderately high	125	65	- -	30		.--	30
High	75	45	---	30	—	---	—
Very high	30	---		30	--	—	—
Potassium fertilizers (K_2O)							
Low	125	65	—	—	--	60	—
Medium	100	50	—	---	---	50	—
Moderately high	75	50	--	—	--	25	—
High	50	50	--.	--	—	—	—
Very high	25	25	—	---	—	—	—

fertilizer application rates and times to treat cotton on typical sierozems with raw cotton ranging from 30 to 35 cent/ha, depending on the mobile phosphorus and potassium contents in the soil according to Machigin. The $N : P_2O_5 : K_2O$ ratio in the mineral fertilizers applied to

sierozems and meadow soils must be 1 : 0.6-0.8 : 0.3-0.5. When cotton is grown immediately after alfalfa, the recommended N : P_2O_5 ratio is 1 : 1.5-2.0. The nutrient ratio in inorganic fertilizers must be adjusted more exactly according to agrochemical indicators of the soil (Table 6.47).

Table 6.47. Nutrient Ratio in Inorganic Fertilizers to Be Applied to Cotton (raw cotton yield of 30-35 cent/ha) Grown on Typical Sierozems (data supplied by the Tashkent affiliate of TsINAO)

P_2O_5 content (mg/100 g of soil) (according to Machigin)	N : P_2O_5 ratio in fertilizers	K_2O content (mg/100 g of soil) (according to Machigin)	N : K_2O ratio in fertilizers
0-1.5 (low)	1 : 0.9	0-10.0 (low)	1 : 0.5
1.6-3.0 (medium)	1 : 0.7	10.1-20.0 (medium)	1 : 0.4
3.1-4.5		20.1-30.0	
(moderately high)	1 : 0.5	(moderately high)	1 : 0.3
4.6-6.0 (high)	1 : 0.3	30.1-40.0 (high)	1 : 0.2
above 6.0 (very high)	1 : 0.1	above 40.0 (very high)	1 : 0.1

A correct fertilizer system for cotton not only increases its yield, but also improves the processing properties of cotton fibre. Within the first year, cotton takes up from inorganic fertilizers 30-60% N, 10-25% P_2O_5, and 30-70% K_2O. The factor of mobile phosphorus utilization (according to Machigin) from the soil is 15 to 30 per cent, and that of mobile potassium (according to Machigin) is 10 to 30 per cent.

Table 6.48 presents the fertilizer system for a 12 course cotton-alfalfa-maize rotation on typical sierozem in Central Asia to attain the following yields: 35-40 cent/ha of raw cotton, 60 cent/ha of grain maize, 500 cent/ha of maize for silage, and 100 cent/ha of alfalfa hay. In this case, it is recommended to treat one hectare of crop rotation fields with an average of 4 to 6 tons of manure and 17 centners of standard fertilizer ($N_{185}P_{122}K_{66}$). The average N : P_2O_5 : : K_2O ratio in inorganic fertilizers is 1 : 0.67 : 0.37, and that in organic and inorganic fertilizers, 1 : 0.65 : 0.45. The approximate nutrient balance in the crop rotation (% of nutrient removal) is: N—130, P_2O_5—215, K_2O—50. Used as row fertilizer is ammophos at a rate of 60 kg/ha.

Table 6.48. Fertilizer System for 12-Course Cotton-Alfalfa-Maize Rotation on Typical Sierozem in Central Asia at Medium Mobile Phosphorus and Potassium Contents in the Soil (raw cotton yield of 35-40 cent/ha)

Crop alternation	Annual fertilizer rate (manure in tons, inorganic fertilizers in kg a.i./ha)				Including										
					basal application				drilling		dressing at the				
	manure	N	P_2O_5	K_2O	manure	N	P_2O_5	K_2O	N	P_2O_5	stage of 2-4 leaves (N)	early budding stage — N	P_2O_5	K_2O	early flowering stage (N)
Maize (silage)+alfalfa		150	280	150		150	270	150		10					
2nd-year alfalfa															
3rd-year alfalfa															
Cotton		120	200	120			120	70	10	30	30	50	50	50	30
Cotton		180	150	90		50	80	50	10	30	40	40	40	40	40
Cotton		250	150	90		70	80	50	10	30	60	60	40	40	50
Cotton	20-30	260	100		20-30	70	70		10	30	60	60			60
Cotton		260	120	90		70	90	50	10	30	60	60		40	60
Maize (grain)		220	140	90		120	130	90		10	50+50 (1st and 2nd dressings)				
Cotton	30-40	250	90		30-40	70	60		10	30	60	60			50
Cotton		250	120	60		70	60	30	10	30	60	60	30	30	50
Cotton		270	120	100		80	60	70	10	30	60	60	30	30	60

Advanced cropping practices have allowed to harvest stable yields of raw cotton over a large area of soils, namely, about 40 cent/ha. For example, in 1975, the average yield over an area of 6750 hectares was 43 cent/ha.

6.9.3 Fertilizer System for Vegetable Crop Rotations

Specific Aspects of Vegetable Nutrition

Vegetable crops require highly fertile cultivated soils with good hydrophysical properties. Most of vegetables are grown on flood plain soils. Most sensitive to the soil solution concentration are such crops, especially when young, as carrots and onions, followed by cucumbers, cabbage, tomatoes, and beet. The optimal concentrations of fertilizers for young plants of cabbage, tomatoes, and beet are, respectively, 1.5, 2.5, and 3 times higher than for cucumbers and 3, 5, and 6 times higher than for carrots. This must be taken into consideration in applying inorganic fertilizers.

Various vegetables are characterized by different nutrient uptake rates throughout the vegetation period. Leaf vegetables (cabbage, lettuce, dock, spinach) require more nitrogen, root crops demand more potassium, tomatoes need more phosphorus, and cucumbers, phosphorus and potassium. Crops grown for winter storage need adequate amounts of phosphorus and potassium. Cabbage intensively takes up nitrogen before its head starts to form, and during head formation it takes up phosphorus and potassium. The most active period of nitrogen and potassium uptake by tomatoes coincides with the fruit bearing stage. The peak of nutrient uptake by cucumbers is at the flowering and fruit formation stages. At the initial growth stage, cucumbers take up more nitrogen and phosphorus than potassium and need almost no nitrogen in the second half of their vegetation period. The nitrogen requirements of onions are high in the first half of the vegetation period, phosphorus and potassium requirements becoming predominant from formation to ripening of bulbs. The nutrient removal by 100 centners of the commercial products of vegetable crops (with due account for their by-products) depends on their biological characteristics as well as soil and climatic conditions (Table 6.49).

Table 6.49. Nutrient Removal by 100 Centners of Commercial Products of Vegetable Crops (kg)

Crop	Soddy podsolic soils			Chernozems			Chestnut soils		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Late cabbage	41	14	49	51	11	52	45	11	56
Carrot	23	10	38	43	14	49	33	11	93
Beet	27	15	43	—	—	—	46	10	116
Tomato	32	11	40	36	7	33	43	8	71
Cucumber	28	15	44	29	12	32	32	10	54
Sweet onion	30	11	29	22	9	29	30	9	39

Response of Vegetables to Soil Solution Reaction and Liming. Depending on their response to soil acidity, vegetable crops are divided into four groups.

1. Beet, cabbage, onions, garlic, celery, spinach, and parsnip do not tolerate high acidity and respond most vigorously to liming.

2. Cauliflower, cucumbers, lettuce, kohlrabi, rutabaga, and leek thrive on weakly acidic soils and respond well to liming.

3. Carrots, parsley, winter and spring radish, turnip, tomatoes, marrow squash, and pumpkin do not tolerate excess calcium and require light liming only when grown on highly and moderately acidic soils.

4. Dock and rhubarb are sensitive only slightly to high acidity and respond weakly to liming.

Vegetables are most sensitive to the mobile aluminium content in the soil. It must not exceed 3-4 mg/100 g of soil and, in the case of some crops (onion, garlic, lettuce, spinach), even 1 mg.

Liming in vegetable crop rotation is performed so that it would produce the most tangible effect on crops highly responsive to liming and the least, on those that do not tolerate excess calcium. In crop rotations including vegetables highly sensitive to soil acidity, sustaining liming produces good results. In this case, the annual liming rate is 1 to 1.5 t/ha or, after a year, 2 to 3 t/ha. It should be remembered that liming makes cabbage less susceptible to clubroot.

Weakly and moderately alkaline soils are treated with

gypsum at a rate of 4 to 6 t/ha. Carrots, onions, and cucumbers do not grow well when the soluble salt content in the soil is 0.2 to 0.3 per cent and that of chlorine exceeds 0.007 to 0.01 per cent. Beet tolerates soluble salt concentrations of up to 0.6-0.7 per cent, while tomatoes and cabbage, up to 0.4 per cent.

Application of Organic Fertilizers

Farms use organic fertilizers chiefly in vegetable crop rotations. In the Non-Black Earth zone, vegetables are treated with 50 to 60 tons of manure or peat-manure compost per hectare, this rate being as high as 80 to 100 t/ha at some farms. On chernozems and chestnut soils, the application rates are lower. Organic fertilizers elicit the best response from crops most sensitive to the soil solution concentration, such as carrots, onions, and cucumbers. It is not recommended, however, to treat carrots and other table root crops (beet, parsley, celery, parsnip, turnip, radish) with fresh and half-decomposed manure because of the possible branching of roots, which adversely affects the integrity, quality, and commercial value of the products. Therefore, table root crops are either treated with fermented manure (20-40 t/ha) or planted two to three years after manuring. Onions are treated only with rotted or, even better, fermented manure (30-40 t/ha), fresh manure being applied to the precursor. Cucumbers, on the contrary, should rather be treated with fresh manure, which, applied at a rate of 60-120 t/ha, supplies cucumbers not only with the basic macro- and micronutrients, but also with carbon dioxide released during its decomposition and readily taken up by leaves. Good results are obtained when manure is applied during autumn ploughing and to late cabbage (30-60 t/ha). Yet manuring of early cabbage is less effective because the vegetation period is too short for manure to decompose to a sufficient degree. This is why vegetables with a long vegetation period should preferably be treated with half-decomposed manure while early vegetables should be treated with rotted manure or be left to the aftereffect of manuring. Tomatoes respond well to organic fertilizers, although their yields on cultivated soils are also high when only inorganic fertilizers are used.

The foregoing suggests that organic fertilizers in vegetable
crop rotations must first of all be applied to cucumbers, then
to onions and cabbage (late and medium late). On sandy and
sandy loam soils, organic fertilizers must be applied in
spring, while on heavier soils, they must be applied during
ploughing in autumn. On flood plain soils, manure is applied
only in spring, primarily to cucumbers.

Application of Inorganic Fertilizers

Depending on the soil type, various vegetable crops are
characterized by a certain order of nutrient minima
(Table 6.50).

Table 6.50. Approximate Order of Nutrient Minima for Vegetable Crops
Grown on Various Soils

Crop	Soddy podsolic soil zone			Leached chernozems	Southern chernozems
	podsolized loams	flood plain soils	low moors		
Cabbage	NKP	KNP	KPN	KPN	PKN
	NPK	NK	KP	NPK	NP
Root crops	NPK	KPN	KN	PK	—
	NKP	KN	K	NK	—
Tomato	PKN	PKN	KP	PKN	PNK
	PNK	PK	K	NPK	P
Cucumber	NKP	KNP	K	NK	PNK
Onion	KPN	KP	K	—	—

The major vegetable crops may be out in the following
order of decreasing effectiveness of inorganic fertilizers:
beet, cabbage, tomato, carrot, cucumber, and onion. According to the results of experiments in various soil and climatic
zones of the USSR, application of complete fertilizer at
rates ranging from 60 to 90 kg/ha of each nutrient increases
yields by an average of 180 cent/ha in the case of cabbage,
120 to 150 cent/ha for beet and carrots, 120 cent/ha for
tomatoes, 110 cent/ha for cucumbers, and 70 to 80 cent/ha
in the case of onions.

In dry farming areas, phosphorus and potassium fertilizers are most often incorporated into the soil by a plough

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with a colter in autumn. Only on sandy and sandy loam soils
is it advisable to apply potassium fertilizers in spring. In
high-rainfall areas, nitrogen fertilizers should also be applied
in spring. However, liquid ammonia fertilizers may be
applied to tenacious soils during autumn ploughing. In
arid and low-rainfall areas, nitrogen fertilizers may be
applied to soils with medium and heavy texture over a deep
water table during ploughing in autumn. Here, preference
is given to ammonia and amide fertilizers over ammonium-
nitrate and especially nitrate ones.

Irrigated tenacious soils are treated with phosphorus and
potassium fertilizers during autumn ploughing even when
water-charging irrigation is performed in autumn. In that
case, nitrogen fertilizers are applied only in spring. Yet,
if no water-charging irrigation is carried out, medium and
heavy soils in low-rainfall regions with a deep water table
can be treated with ammonia and amide fertilizers, during
ploughing in autumn.

Phosphorus and potassium fertilizers are used for basal
application to flood plain soils and drained peat bogs in
spring. Application in autumn entails heavy nutrient losses
due to their leaching by melt water.

The following fertilizer rates are recommended for starter
application to vegetables: $N_{10}P_{20}K_{10}$ for tomatoes and
$N_{10}P_{10}K_{10}$ for carrots, onions, cucumbers, and beet. In
this case, either phosphorus alone in the form of pelletized
superphosphate is used or two or three nutrients at a time
in the form of compound and combined fertilizers. The
starter fertilizer is most effective when placed 2 to 3 cm
below seeds and 2 to 3 cm aside from the row. When seedlings
are transplanted, fertilizers are applied with irrigation
water (solution concentration up to 0.2%).

Dressing is not an adequate substitute for basal fertilizing
and is normally regarded as a supplementary procedure.
It should involve primarily nitrogen and potassium fertil-
izers, while phosphorus ones should be used before seeding
or planting. Dressing is done under the following circum-
stances: (a) on light soils of high-rainfall regions; (b) in
the case of frequent irrigation at high rates and long vegeta-
tion periods; (c) at high inorganic fertilizer rates when their
bulk application can considerably raise the soil solution

concentration and thereby inhibit the development of plants (carrots, onions, cucumbers); (d) when the soil did not receive enough fertilizer before seeding.

Whenever necessary, dressing should be performed once to three times over the vegetation period. The first dressing is usually carried out 30 to 35 days after seeding of vegetables (with appearance of the third true leaf) or 12 to 20 days after transplantation of the seedlings. The subsequent dressings follow some two to three weeks later. The fertilizers are incorporated by a side dresser to a depth of 5 to 8 cm, 6 to 8 cm aside from the plant, during the first dressing and to a depth of 10 to 12 cm, in the middle between rows, during the second. In the case of irrigation, they are incorporated by a side dresser before watering.

Good results are obtained when the dressing is done with irrigation water using special sprinklers. Dissolved fertilizers are distributed over the field from the sprinkler. The average fertilizer concentration in irrigation water must be 0.1 to 0.2 per cent, and the maximum one, 0.5 per cent. The plants are first sprinkled with clean water, then with the fertilizer solution, and again with clean water for 5 to 10 minutes in order to wash the fertilizers off leaves. Fertilizers should not be dissolved in irrigation canals to avoid their wastage and contamination of the neighbouring water bodies.

The following nutrient rates are recommended to dress vegetables: $N_{20-40}P_{20-40}K_{20-40}$ for the first dressing and N_{20-40}-K_{20-60} for the second and subsequent dressings. Whether dressing is needed or not can be determined from the results of chemical analysis of the plants as well as quick analysis by the Zerling-Magnitsky method.

The nitrogen fertilizers most commonly applied to vegetable crops are ammonium nitrate, urea, and ammonium sulphate. The latter two are especially good for irrigated fields. Sodium nitrate is most effective when applied to table root crops and tomatoes. The best phosphorus fertilizer for vegetables is superphosphate. Cauliflower can be treated most effectively with molybdic and boronated superphosphate. The most commonly used potassium fertilizer is potassium chloride. Potassium sulphate is applied chiefly to cucumbers, tomatoes, and onions grown mostly in green-

houses. Table beet, carrots, radish, rutabaga, turnip, parsley, celery, and cabbage respond well to sodium. This is why they can be treated with potassic salt. When applied in autumn, chlorine is leached out of the soil and does not harm plants. Of all vegetable crops only table beet tolerates excess chlorine. On sandy and sandy loam soils, magnesium-containing potassium fertilizers are preferable.

Joint Application of Organic and Inorganic Fertilizers

The productivity of vegetable crop rotations is the highest when organic and inorganic fertilizers are applied together. Manure should first of all be supplemented with nitrogen fertilizers, especially on soddy podsolic soils.

Table 6.51. Fertilizer Rates for Vegetable Crops Grown on Soddy Podsolic and Flood Plain Soils with Medium Mobile Phosphorus and Potassium Contents (manure and compost in tons, inorganic fertilizers in kg a.i./ha)

Crop	Estimated yield (cent/ha)	Soddy podsolic soils				Flood plain soils			
		manure	N	P_2O_5	K_2O	manure	N	P_2O_5	K_2O
Early cabbage*	300		90	20	30		60	40	90
	500		150	60	90		120	80	150
Medium late and late cabbage	400	40	120	40	90	30-40	90	40	150
	800	40	240	120	210	30-40	150	120	270
Carrot	300		30*	40*	60*		30	60	90
	500		90*	80*	120*		90	80	150
Beet	300		90	40	120		60	40	150
	500		150	100	180		120	80	210
Tomato	200		90	140	90		60	120	120
	300		120	160	120		90	140	150
Cucumber	200	80	60	80	90	60-80	60	60	90
	300	80	90	100	120	60-80	90	80	120
Common onion*	200		90	60	90		90	60	60
	300		120	80	90		120	80	90

* In addition to the aftereffect of 40 to 60 tons of manure (compost) on soddy podsolic and low-humus flood plain soils.

Table 6.52. Fertilizer Rates for Vegetable Crops Grown on Chernozems and Chestnut Soils with Medium Mobile Phosphorus and Potassium Contents (manure in tons, inorganic fertilizers in kg a.i./ha)

Crops	Estimated yield (cent/ha)	Leached and typical chernozems				Southern chernozems and chestnut soils			
		manure	N	P_2O_5	K_2O	manure	N	P_2O_5	K_2O
Early cabbage	200-300		60	60	60		75	45	60
	300-400		90	80	90		90	60	75
Medium late and late cabbage	200-300		90	60	90		90	45	60
	400-500		150	100	120		150	75	90
Carrot	200-300		60	60	60		60	45	45
	400-500		90	80	90		100	70	70
Beet	200-300		60	40	60		60	45	45
	300-400		120	60	90		90	70	60
Cucumber	100-200	20-40	60	60	30	20-40	75	45	30
	200-300	20-40	90	75	60	20-40	90	60	60
Tomato	200-300		60	100	45		90	80	30
	300-400		90	140	60		120	90	60

Table 6.53. Fertilizer System for Eight-Course Vegetable Crop Rotation on Irrigated Soddy Podsolic Light Loamy Soil with Average Mobile Phosphorus and Potassium Contents (manure in tons, inorganic fertilizers in kg a.i./ha)

Crop alternation	Estimated yield (cent/ha)	Basal application				Starter application			Dressings 1st		2nd	
		manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	K_2O	N	K_2O
Oat + grasses	35		40	120	200		10					
1st-year grasses (hay)	60											
2nd-year grasses	60								40			
Late cabbage	600		100	160	200				40	40	40	40
Cucumber	250	80					10					
Tomato	300								30			
Table root crops	400		40	60	110	10	10	10	20			
Medium late cabbage	500	50	60	40	60					40		

Table 6,54. Fertilizer System for Eight-Course Vegetable Crop Rotation on Irrigated Soddy Podsolic Light Loamy Soil with Average Mobile Phosphorus and Potassium Contents (manure in tons, inorganic fertilizers in kg a.i./ha)

Crop alternation	Estimated yield (cent/ha)	Basal application				Starter application			Dressing 1st		2nd	
		manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	K_2O	N	K_2O
Medium late cabbage	600		100	150	150				40	40	40	60
Tomato	300		30	90	30				30	20	30	30
Cucumber	250	60	30	20	30		10				30	30
Late cabbage	800		100	150	200				40	40	40	60
Beet	400			50	130	10	10	10	20	30	30	40
Carrot	500		60	80	100	10	10	10	20	20	30	30

Soviet research institutions have worked out recommendations as regards application of fertilizers to vegetable crops in various soil and climatic zones, depending on the estimated yield and agrochemical indicators of the soil (Tables 6.51 and 6.52).

At some farms, unreasonably high inorganic fertilizer rates are applied to vegetables to increase their yield, which

Table 6.55. Fertilizer System for Vegetable Crop Rotation in the Irrigated Parts of Central and Western Kuban (manure in tons, inorganic fertilizers in kg a.i./ha)

Crop alternation	Basal application				Starter application			Dressing		
	manure	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Spring cereals + grasses		40	130	120		10				
1st-year grasses										
2nd-year grasses										
Tomato		30	90	60				30		30
Cucumber	30					10		30		
Onion			60	40				30		20
Tomato		50	90	60				30		30
Medium late and late cabbage	30	60	90	60				30		30
Beet, carrot					10	10	10	20	20	20
Tomato	20	30	90	60				30		30
Early cabbage		60	90	60				30		30

Note. The vegetable yields are as follows: 250-300 cent/ha of onions and cucumbers, 350-400 cent/ha of tomatoes, 400-450 cent/ha of table root crops, 300-350 cent/ha of early cabbage, and 600-700 cent/ha of medium late and late cabbage.

may impair the product quality (increase the nitrate content) and polute the environment.

Fertilizer systems for vegetable crop rotations are given in Tables 6.53 through 6.55.

6.9.4 Fertilizer System for Orchards

The fertilizer system for orchards and bush-fruit (raspberry, currant, gooseberry) gardens comprises the following stages: (1) Treatment of fruit-crop and bush-fruit nurseries. (2) Soil cultivation before establishing an orchard or bush-fruit garden. (3) Fertilizer application during planting of fruit trees and bushes. (4) Treatment of the young orchard. (5) Treatment of the fruit-bearing orchard.

Treatment of strawberry includes fertilizing of the nursery and that of the plantation in special crop rotations.

Specific Aspects of Nutrition of Fruit and Berry Crops

In their growth, fruit trees go through the following five development stages: (1) intensive vegetative growth till the first fruitage, when the above-ground part and roots grow rapidly; (2) growth and fruitage (from the first fruitage to commercial harvest), this period being characterized by steady yield increases from one year to another, marked progressive growth of primary branches and increasing number of fruit-bearing elements on them; (3) fruitage and growth (from the first commercial harvests to the highest yields), when the progressive growth slows down, the expansion of primary branches is reduced in scope, and the early generations of tertiary branches in the centre of the tree crown start dying away: (4) fruit bearing at a maximum rate, characterized by cessation of growth and accelerated dying away of tertiary branches; (5) cessation of fruit bearing as well as extensive dying away of tertiary, secondary, and primary branches with simultaneous emergence of innovation shoots on old primary branches.

Corresponding to each development stage is a particular nutrient uptake rate, which must be taken into account in determining the fertilizer rates for fruit crops. The most efficient from the economical standpoint is the third stage when fruitage and growth are in an ideal relationship.

The annual cycle of fruit trees, is, in turn, divided into four periods: two long (vegetation and relatively dormant) periods and two short (from vegetation to dormancy and from dormancy to vegetation) ones. Hence, two stages of

nutrient uptake during the vegetation period are distinguished for fruit trees, the first stage falling between the beginning of vegetation and the cessation of shoot growth and harvesting, while the second stage occurs after harvesting to late autumn. The first stage involves growth of shoots and leaves, formation of fruits and berries, as well as initiation of fruit buds for the next year's harvest. It is marked by a predominant uptake of nitrogen at the expense of the nutrients. The second stage coincides with the second peak of root growth, continuing development of the fruit buds for the next year's harvest, expansion of the trees' girth, and deposition of storage nutrients. At this stage, trees require moderate nitrogen nutrition and enhanced phosphorus and potassium uptake increasing the frost resistance of trees.

The roots of pear trees extend deeper than those of apple trees, the roots of cherry, sweet cherry, and plum trees are more shallow than those of pip fruit trees.

The diameter of the soil circle occupied by roots is one and a half to two times greater than that of the tree crown. The diameter of the root habit around the trunk is at least 2 m in the case of 3- to 4-year-old trees, 3 m with 5- to 6-year-old trees, 4 m for 7- to 8-year trees, and so on (the age of a tree divided by two).

The vertical roots of fruit trees reach a depth of 10 m. The root density within the area confined by the projection of the tree crown is usually three to four times higher than beyond its limits. In fruit trees and bushes, every main root is associated with a certain part of the above-ground system. Hence, fertilizers should preferably be applied evenly around the plants.

The growth of fruit plants is strongly inhibited by an increased content of water-soluble salts and exchangeable sodium in the soil. According to Negovelov, when the content of harmful salts (all water-soluble salts of the soil except for calcium bicarbonate, gypsum, and nutrients) exceeds 2 meq/100 g of soil in the one metre-thick layer, 3 meq in the 100-160 cm-thick layer, and 5 meq below three metres, these soils cannot sustain orchards. The limiting concentration of exchangeable sodium in the soil is 10 per cent for apple trees, 13 per cent for apricot trees, and 15 to 20 per cent for quince trees, of the overall exchange capacity. As

regards the response of fruit and berry crops to the soil solution reaction, they can be divided into three groups: (1) crops requiring a neutral reaction, such as cherry, sweet cherry, plum, peach, and apricot; (2) crops thriving at a weakly acidic reaction, such as apple, pear, gooseberry, and currant; and (3) crops tolerant to a moderately acidic reaction, such as raspberry and strawberry.

The annual removal of nutrients by different young fruit trees varies widely: 6 to 44 kg/ha in the case of nitrogen (N), 2 to 7 kg/ha in the case of phosphorus (P_2O_5), and 6 to 35 kg/ha in the case of potassium (K_2O). Table 6.56 illus-

Table 6.56. Annual Nutrient Uptake by Fruit-Bearing Trees and Bushes

Crop	Yield (cent/ha)	Uptake (kg/ha) of			
		N	P_2O_5	K_2O	CaO
Fruit-bearing apple	615	67	18	72	73
Young pear	220	34	8	38	44
Young plum	99	34	10	44	47
Peach	234	85	20	82	130
Quince	210	52	17	65	74
Red currant	201	133	51	82	174
Black currant	73	63	25	34	94
Gooseberry	180	79	40	123	96
Strawberry	108	156	35	184	—

trates annual rates of nutrient uptake by fruit-bearing crops. At the stage of rapid shoot growth, apple trees extract more phosphorus than nitrogen and potassium. When the growth slows down, nitrogen and potassium are, on the contrary, taken up four to five times more vigorously than phosphorus. Yet, at the stage when the growth ceases, phosphorus is taken up in the first place, followed by potassium and nitrogen whose uptake is much lower.

In the case of raspberry, the period of intensive nitrogen, phosphorus, and potassium uptake is protracted, extending all the way to late summer, then discontinue abruptly.

In the case of gooseberry, the growth till the end of blooming is sustained mainly by the storage nutrients deposited

Table 6.57. Classification of Soils According to Mobile P_2O_5 and K_2O contents (mg per 100 g of soil) for Fruit and Berry Crops (as recommended by the TsINAO and the Michurin USSR Research Institute of Horticulture)

Mobile P_2O_5 or K_2O content in the soil	According to Kirsanov and Chirikov		According to Machigin		According to Oniani	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
P_2O_5						
Low	< 8	< 4	< 2	< 1	< 20	< 11
Medium	8–12	4–6	2–3	1.1–1.6	20–30	11–16
Moderately high	12–16	6–8	3–4	1.7–2.2	30–40	17–22
High	16–20	8–10	4–5	2.3–2.8	40–50	23–28
Very high	> 20	> 10	> 5	> 2.8	> 50	> 28
K_2O						
Low	< 7	< 3	< 15	< 7	< 9	< 6
Medium	7–10	3–6	15–21	7–10	9–13	6–8
Moderately high	11–14	6–9	22–28	11–14	14–20	9–10
High	15–18	9–12	29–35	15–18	21–25	12–14
Very high	> 18	> 12	> 35	> 18	> 25	> 14

Note. The mobile potassium content is given for moderately loamy soils.

the year before. The period after blooming to the end of fruit formation is marked by intensified uptake of nutrients, primarily nitrogen. In August and September, the nutrient uptake comes to a virtual halt.

Before blooming, strawberry takes up 15 to 20 per cent of the total nutrients it receives over the vegetation period. From early blooming to late fruitage (i.e. over a period of 1.5 months), it takes up 40% N and 55% P_2O_5 and K_2O. From the end of fruitage to removal of runners, strawberry takes up about 20 per cent of its nutrients, and after removal of the runners, it takes up 15% N and 2 to 7% P_2O_5 and K_2O. The peak of phosphorus and potassium uptake (about 40%) by strawberry coincides with the fruitage period (three weeks). The nitrogen uptake by this crop is protracted in time and is evenly distributed among the vegetation stages.

For classification of soddy podsolic and grey forest soils according to phosphorus and potassium content for horticultural crops, see Table 6.57.

Moderately and heavily loamy soils (0-20-cm layer) are classified as follows in terms of mobile magnesium content (mg MgO per 100 g of soil): low, i.e. less than 5, medium, 6 to 9; increased, 9 to 12; high, 12 to 15; and very high, i.e. exceeding 15.

Orchard soils undergo agrochemical analysis once in four to five years, which forms the basis of rational application of fertilizers in accordance with the resulting charts. The fertilizer rates may be calculated or average rates recommended by research institutions and adjusted depending on the mobile nutrient content in the soil are used. For example, at low and very low contents of a nutrient, the correction factor to the average rate is 1.3 to 1.5, at a medium content, 1.0, at an increased content, 0.75, at a high content, 0.5, and at a very high content, 0.25.

The nutrient requirements of fruit and berry crops can be determined by the method of leaf diagnosis (Table 6.58). Leaves are taken for analysis from fruit trees after cessation of shoot growth (in the second half of the vegetation period), in the case of bush fruits, leaves are taken during their ripening, and for strawberry, during vigorous blooming and fruit formation. The analysis sample is taken out of 40 to 50 leaves from the middle of the current year's growth in the

Table 6.58. Optimal Nutrient Content in Leaves of Horticultural Crops ($\%$ dw)

Crop	N	P_2O_5	K_2O	CaO	MgO
Apple, pear	1.8-2.5	0.3-0.5	1.2-1.8	1.4-2.0	0.4-0.6
Cherry, plum, sweet cherry	1.8-2.5	0.3-0.5	1.6-2.4	1.8-2.8	0.4-0.6
Currant	2.2-3.4	0.5-0.7	1.6-2.4	1.8-2.8	0.3-0.5
Gooseberry	2.1-3.1	0.5-0.7	1.6-2.4	1.8-2.8	0.4-0.6
Raspberry	2.3-3.5	0.5-0.7	1.3-1.9	1.5-2.3	0.4-0.6
Strawberry	2.0-3.0	0.5-0.7	2.0-3.0	2.3-3.5	0.2-0.4

case of fruit trees, gooseberry, and raspberry, from the middle of root or continuance shoots of black currant, and developed leaves from the middle of the plant in the case of strawberry. When the nutrient content in leaves is below optimal, appropriate inorganic fertilizers should be applied to the fruit and berry crops already in the current year to ensure a good yield. If the nutrient content is optimal, dressing of crops to be harvested in the current year is not done. Chemical diagnosis of leaves of fruit and berry crops in July or August permits adjusting the fertilizer rates for the next year's harvest. To this end, the recommended or accepted fertilizer rate is doubled if the nutrient content is too low (more than 35% below optimal), increased 1.5-fold if the nutrient content is low (20% below optimal), left the same if the nutrient content is optimal, and no fertilizers are applied if the nutrient content in leaves is increased (20% above optimal).

Workers of the Michurin USSR Research Institute of Horticulture recommend to apply an integrated correction factor to the average annual fertilizer rate according to the nutrient contents in the soil and in leaves (Table 6.59). In the absence of charts showing the content of mobile nitrogen in the soil, the nitrogen fertilizer rate is adjusted according to the findings of leaf diagnosis.

Treatment of horticultural crops with fertilizers must be based on their biological characteristics at different stages of their development, the nutrient balance in the soil, the aftereffect of the organic, phosphorus, and potassium fertiliz-

Table 6.59. Correction Factors to Be Applied to Average Annual Rates of Phosphorus, Potassium, and Magnesium Depending on the Content of These Nutrients in the Soil and in Leaves

Mobile nutrient content in the soil	Nutrient content in leaves		
	insufficient	optimal	excessive
Very low and low	2.0	1.5	—
Medium and moderately high	1.5	1.0	—
High	1.0	0.5	—
Very high	0.5	—	—

ers applied earlier and, consequently, changes in the nutrient ratio in inorganic fertilizers over many years of their application, as well as weather conditions and farming practices. For example, fertilizer rates, especially in the case of nitrogen fertilizers, are increased (1.5-2 times) in sodded orchards and decreased when trees are pruned considerably. In a cold and humid year, the rate of nitrogen fertilizers is 20 to 30 per cent higher, and in a dry and warm year two to three times lower, than in a normal year. In the second and subsequent years after a routine agrochemical analysis has been made, the rates of phosphorus fertilizers used in orchards are reduced by a factor of 1.5 to 2 and those of potassium fertilizers are reduced by a factor of 1.3 to 1.5 with respect to the rate established from the agrochemical indicators of the soil in the year of analysis. When the soil receives enough organic fertilizers before planting, the recommended rates of inorganic fertilizers are reduced by a factor of 1.5 to 2 over a period of five to seven years after planting. Horticulturists must give special attention to the supply of fruit and berry crops with micronutrients, which can be assessed through analysis of their leaves. When the median leaves of shoots (after cessation of growth) contain less than 6 mg of zinc, 10 mg of copper and manganese, and 15 mg of boron per kg dw, appropriate micronutrient fertilizers must be applied. It should be borne in mind that overnutrition with potassium inhibits the uptake of not only calcium, magnesium, and iron but also many micronutrients,

whereas application of phosphorus fertilizers at excess rates makes boron, zinc, and copper less available.

Thus, in intensive horticulture, balanced nutrition plays an important role in enhancing the productivity of fruit and berry crops. Its importance becomes more pronounced when inorganic fertilizers are applied at heavy annual rates in highly productive orchards with reduced rates of organic fertilizers. Balanced nutrition makes plants less prone to various functional diseases and permits increasing yields as well as the quality of crops.

Application of Fertilizers in Fruit and Berry Crop Nurseries

A nursery usually consists of three sections: (1) propagation section (planting, lining-out cutting, and layering plots); (2) transplant training section; and (3) seed plantations supplying the nursery with seeds to grow the seedling stock, to produce grafts, suckers, layers, and the like.

Propagation (seeding) and. training (transplant) sections involve separate crop rotations.

To cultivate the soil prior to establishment of the nursery (seedling and transplant sections), it undergoes tillage with a deep plough (to a depth of 30 to 45 cm). Soddy podsolic soils are ploughed to a depth of 25 to 30 cm with subsoiling to another 10 to 15 cm. Here 30 to 100 t/ha of organic fertilizers are applied (depending on the soil type) and phosphorus-potassium fertilizers are incorporated at the rate $P_{60-120}K_{60-120}$ depending on the agrochemical properties of the soil. Acid soils are treated with lime (preferably twice: during ploughing in autumn and cultivation in spring). Field crops in crop rotation are treated depending on the estimated yields and biological characteristics of the crops. After two to three years of soil cultivation, when field crops are sown, the plots are used to grow seedlings and to train transplants.

To grow seedlings (seedling section), 20 to 50 t/ha of half-decomposed or well-rotted manure together with $P_{60-90}K_{60-90}$ are applied during autumn ploughing (or to the precursor). Chernozems are treated with manure at a rate of 20 to 30 t/ha, the manuring rate of soddy podsolic soils

being as high as 50 t/ha. When fruit crops are seeded, the rows are treated with pelletized superphosphate at a rate of 20 kg P_2O_5 per hectare. Preferably, the seeds and fertilizer should be separated by a 1-2 cm soil layer.

Addition of nitrogen to the row phosphorus fertilizer produces negative results. Once the seedlings are strong enough (at the stage of three to four true leaves), they are dressed with nitrogen at a rate of 30 to 45 kg/ha. The second dressing with nitrogen at the same rate is performed early during intensive growth of the seedlings, but not before 15 to 20 days elapse since the first dressing. If nitrogen fertilizers are applied together with water, the concentration of the solution during the first dressing must range from 0.10 to 0.15 per cent, and during the second dressing it must not exceed 0.2 per cent. The seedlings can be dressed with manure water and poultry manure. Manure water is first diluted with water five to ten times, then poured into burrows 4 to 5 cm deep, between rows (at a rate of one watering can per 3 to 4 m or, in other words, 10-15 t/ha). Poultry manure is first steeped in water (one part of manure for two parts of water) for several days, then diluted with water eight to ten times immediately before application. Its application rate is 8 to 10 cent/ha.

The seedling stock grown in the propagation (seedling) section is transferred to the *training (transplant) section.* The latter is ploughed in autumn with subsoiling and, if necessary, treated with manure at a rate of 30 to 60 t/ha (which may also be applied to the precursor) and with $P_{120-150}K_{120-150}$. Before they enter the period of intensive growth, seedling trees are dressed in spring with nitrogen fertilizers at rates ranging from 30 to 45 kg N/ha. After a month, the dressing is repeated. In the second field of the nursery, occupied by yearlings, the first dressing with nitrogen (N_{30-60}) is performed in early spring, followed by a second dressing at the same rate as soon as the seedlings reach the height of 15 to 20 cm, that is, at the beginning of their intensive growth. The third field of the nursery with two-year-old trees is fertilized as required. If it has been treated with phosphorus and potassium fertilizers earlier, only nitrogen fertilizers are applied.

Seed plantations of fruit and berry crops in nurseries are treated in the same manner as an ordinary fruit-bearing orchard (see below).

Soil Cultivation Before Establishment of an Orchard and Bush-Fruit Gardens

The soil starts being cultivated three to four years before fruit trees and shrubs are planted. First of all, the plot is tilled with a deep plough (Table 6.60). In the case of soddy podsolic soils where the ploughing depth is less as compared to other soils, subsoiling to another 10 to 15 cm is done. The ploughing is preceded by application of organic fertilizers (40-100 t/ha), lime, and phosphorus-potassium fertilizers (the latter being placed in reserve for several years). In some instances, the soil should be treated with ground phosphate rock at a high rate of 10 to 25 cent/ha. Liming is done through the entire arable layer. It is advisable that two thirds of the lime rate be ploughed down with the rest being incorporated by a cultivator into the topsoil. For cultivation to be accomplished within as short a period of time as possible, the topsoil should also receive 30 to 40 tons of organic fertilizers per hectare. After that, the plot is seeded with perennial legumes or legume and grass mixtures.

Sandy loam soils are seeded with lupine grown for use as green manure. Grasses are seeded over a two-year period, the plot is ploughed in the last year after the first cutting to a depth of 20 to 25 cm, the soil is properly turned, and the orchard is planted. If for some or other reason the soil could not be cultivated in advance, the cultivation is done between tree rows after the orchard has been planted. In this case, organic, inorganic, and lime fertilizers are applied before the orchard is established and ploughed down to a depth of 20 to 25 cm.

Before establishment of thick orchards, the preplanting fertilizer should preferably be spread over the entire orchard area. Prior to establishment of orchards with widely spaced rows of trees (especially when the farm does not have enough fertilizers, particularly organic ones, for the entire area to be treated), organic and inorganic fertilizers may be applied

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in strips (1-1.5 m wide) along the future tree rows with subsequent cultivation of the soil between the rows.

The fertilizer rates in strip application (per hectare of a strip) are the same as in overall application.

When an orchard has to be established within a short period of time without preliminary cultivation of the soil, fertilizers **are** applied only during planting into trenches,

Table 6.60. Preplanting Ploughing Depth and Rates of Organic and Inorganic Fertilizers for Various Horticultural Zones (manure and compost in tons, inorganic fertilizers in kg a.i./ha)

Crop	Depth (cm)	Manure, compost	P_2O_5	K_2O
Northern zone (soddy podsolic soils)				
Fruit trees	40-50	40-80	150-300	120-400
Bush fruits	35-40	40-100	100-300	100-300
Strawberry	25-30	40-80	60-150	60-150
Central zone (grey forest soils and chernozems)				
Fruit trees	60	20-40	150-300	120-200
Bush fruits	40-50	40-50	120	90
Strawberry	35-40	50-60	90-120	60-90
Southern zone (chestnut soils and southern chernozems)				
Fruit trees	65-70	30-40	100-150	100-150
Bush fruits	50	25-30	120	60-90
Strawberry	40	30-40	90-120	30-60

furrows, or planting holes, and the subsequent cultivation of the soil between tree rows is carried out gradually over a period of several years.

The recommended rates of phosphorus, potassium, and organic fertilizers for preplanting application (Table 6.60) are adjusted using correction factors (see p. 269) depending on the mobile phosphorus and potassium contents in the soil (Table 6.57). In this case, the organic fertilizer rate usually varies with the mobile phosphorus content in the soil.

Organic and inorganic fertilizers, especially phosphorus and potassium ones, should be incorporated into deep soil layers so that they find themselves in the root zone and are better utilized by fruit crops. During the fruit-bearing period, deep incorporation of fertilizers into the soil is extremely difficult, which is why reserve application of phosphorus and potassium fertilizers in the soil of orchards has been steadily gaining in importance. For example, it has become standard practice in Moldavia to apply 60 to 120 t/ha of manure and 300 to 600 kg/ha of phosphorus and potassium, depending on the mobile P_2O_5 and K_2O contents in the soil, during trench ploughing prior to orchard establishment.

During preplanting cultivation of the soil, a great deal of attention should be given to weed control by mechanical means in combination with herbicides used for treatment of the field crops grown on this area. In the case of heavy infestation, especially with ill perennial cereal weeds, mechanical weeding of clean fallow should be combined with joint treatment with TCA, dalapon, and 2,4-D.

Fertilizer Application During Planting of Fruit Trees and Bushes

Of great importance apart from soil cultivation prior to orchard establishment is also localized application of fertilizers during planting of fruit trees and bushes. In the case of mechanical planting of currant, gooseberry, and raspberry, it is often sufficient to stockpile enough fertilizer in the soil during preplanting cultivation of the latter without applying fertilizers immediately before planting.

In modern commercial orchards, trench planting of fruit trees is common. A trench 45 to 60 cm deep and 40 to 50 cm wide is cut by a deep plough twice in a single direction along the axis of the future row of trees. In this case, organic fertilizers (fermented manure, seasoned compost, or non-acid low peat) are in most cases placed before the trench is cut, in a strip along the latter.

Under different circumstances, other alternatives are possible when fertilizers are placed on the bottom of the cut trench or divided into two equal portions, one half being placed before the trench is cut and the other, on the trench bottom. Nitrogen fertilizers are not used in trench planting, while phosphorus and potassium fertilizers should preferably be placed on the trench bottom. After the trench has been backfilled (using a bulldozer with a special attachment), transplants are planted in a mechanized manner and holes are made for watering. Each transplant receives 20 to 30 litres of water, then the rings around the trees are mulched with peat, compost, manure, or loose earth.

A trench 100 m long accommodating pip and stone fruit trees receive 800 to 1200 kg of organic fertilizers, 8 kg P_2O_5 (40 kg of ordinary superphosphate), and 2.5 to 3 kg K_2O (4.5-5.5 kg of potassium chloride) on soddy podsolic soils and 400 to 800 kg of organic fertilizers, 4 to 6 kg P_2O_5, and 1.5 to 2.5 kg K_2O on chernozems and chestnut soils.

Proceeding from the recommendations as regards placement of fertilizers in planting holes, one can easily calculate the fertilizer rate for a square metre of the trench soil. To do this, the rates of organic and inorganic fertilizers (Table 6.61) are doubled for pip fruit crops, multiplied by five for stone fruit crops, and by ten for bush fruits.

When currant, gooseberry and, especially, raspberry are planted, good results are attained by placing organic fertilizers in furrows cut by a plough. This is followed by mechanized planting of bushes.

Mechanized transplantation of strawberry does not call for localized application of fertilizers; instead, they are spread over the entire plot before transplantation.

Table 6.61. Rates of Organic and Inorganic Fertilizers to Be Placed in a Planting Hole in Orchards and Bush-Fruit Gardens (kg) (according to Spivakovsky)

Fertilizer	Soddy podsolic soils				Chernozems and chestnut soils		
	pip fruit crops	stone crops	fruit	bush fruits	pip fruit crops	stone fruit crops	bush fruits
Manure (fermented), compost, humus	20-30	10-12		8-10	10-20	8	4-6
Potassium chloride (or)	0.1	0.05		0.03	0.06	0.04	0.02
potassium sulphate	0.15	0.06		0.04	0.08	0.05	0.03
Superphospate	1.0	0.4		0.2	0.5]	0.3	0.15
(or) ground phosphate rock	1.5	0.6		0.3	—	—	—
Ammonium nitrate	0.06	0.04		0.02	0.06	0.04	0.02
Crushed limestone or dolomite	0.6-1.0	0.3-0.4		0.1-0.15	—	—	—
Total inorganic fertilizers (g a.i.):							
N	21	14		7	21	14	7
P_2O_5	200	80		40	100	60	30
K_2O	60	30		18	36	24	12

Fruit trees and bushes are currently planted into holes made by digging machines (holes 20 to 100 cm in diameter and 60 to 70 cm deep) or by hand only on small plots or during replacement of trees or bushes.

Soil cultivation throughout the planting hole volume is important for the transplants to take root and for the young orchard to reach the fruit-bearing stage within a shorter

period of time. The following planting hole dimensions are recommended for soils of moderate fertility:

Crops	Diameter, cm	Depth, cm	Volume, m³
Apple, pear	100	60	0.5
Cherry, plum	80	40	0.3
Bush fruits	50-60	30-35	0.1

On poor soils, the hole diameter is increased by at least 25 to 30 per cent. After the transplants have been inserted into holes, the latter should preferably be backfilled only with the topsoil taken from between tree rows (if no trenching has been peformed there), while the soil removed from the hole should be scattered between tree rows. When all of the soil removed from the hole is used to plant a tree, the bottom portion of the hole should receive more topsoil and less subsoil, this order being reversed for the upper part. The root system of a tree is covered only by the topsoil.

Experiments have shown that the optimal fertilizer rate for planting fruit trees is 15 g of humus and 0.03-0.05 g NPK per kg of soil from the hole. Some workers suggest that organic, inorganic, and lime fertilizers should be uniformly mixed with all of the soil from a planting hole. Spivakovsky recommends to mix half-decomposed manure, compost, or humus with the entire hole contents, to place two thirds of the inorganic fertilizer to be applied together with organic fertilizers on the hole bottom which is turned over, then to mix the remaining third of the inorganic fertilizer with the soil that fills the lower half of the hole. If peat is used, it is to be mixed with all of the soil removed from the hole. Such placement of inorganic fertilizers rules out inhibition of the transplant.

If the soil has been limed at full rate before establishment of the orchard, lime is added during planting only to the hole soil layers unaffected by liming.

Slightly decomposed manure should not be placed in planting holes because this may prevent transplants from taking root. If such manure is incorporated to a great depth, it decomposes under anaerobic conditions and yields noxious underoxidized compounds. Table 6.61 lists fertilizer rates for planting holes whose dimensions were specified above. If the hole volume is increased, the rates of the fertilizers to

be placed in the hole should be raised accordingly. When superphosphate is placed in combination with ground phosphate rock, one part of the former is taken equal to two or four parts of the latter. The overall rate of inorganic fertilizer nutrients to be received by a planting hole depends on the soil type and is (in g a.i.) $N_{20}P_{100-200}K_{40-60}$ for pip fruit crops, $N_{15}P_{60-80}K_{20-30}$ for stone fruit crops, and $N_7P_{30-40}K_{10-20}$ for bush fruits. When the planting is done in dry spring weather, it is recommended to put the transplant into water or an earth-water mixture a day or several hours before planting. After planting, each tree receives 20 to 30 litres of water. As soon as the water is imbibed, the ring around the tree is covered with dry earth and mulched with peat (4-5 cm layer), manure, or compost (15-20 kg per tree). If enough fertilizer has been applied in reserve before planting, orchards and bush-fruit gardens can stay untreated for three to five years. In thick orchards, this period is shorter.

Treatment of the Young Orchard

Treatment of young orchards boils down to placement 🐟 fertilizers around trees and between their rows. Rings around trees are kept only as clean fallow. It is even better to mulch them with peat or compost. The row spacings in young orchards are used for cultivation of potatoes, vegetables, fodder root crops, annual legumes, honey plants, and, in high-rainfall regions, also perennial legumes and cereal grasses. The fertilizer system for row crops must ensure a drastic increase in soil fertility with a view to raising fruit crop yields. Soils of light and medium texture are sown with such green manure crops as lupine, mustard, vetch-oat mixture, and phacelia. If fertilizers have been placed in planting holes, young trees are not treated in the year they are planted. Fertilizers are placed in the second and later years depending on the state of cultivation of the soil in the planting hole.

Depending on the prevailing soil and climatic conditions as well as species and age of the trees, the recommendations are that one square metre of the ring around a tree should receive, along with 3 to 4 kg of organic fertilizers, 3 to 6 g N, 4 to 6 g P_2O_5, and 2 to 5 g K_2O. Higher rates are applied to

poor soils and in irrigation farming regions; lower rates are used when soils are fertile and in low-rainfall areas. Application of 3 to 4 kg of organic fertilizers per square metre is equivalent to a rate of 30 to 40 t/ha, and that of 2 to 6 g a.i. of inorganic fertilizers per square metre corresponds to a rate of 20 to 60 kg of their nutrients per hectare. Depending on its age (3-13 years) and the soil and climatic conditions, a tree receives 10 to 80 kg of manure, 15 to 120 g N, 15 to 120 g P_2O_5, and 10 to 100 g K_2O.

When organic and inorganic fertilizers are used separately, their rates are increased by a factor of 1.5. Young trees grown on poor soils are treated once a year, while those grown on adequately cultivated soils are fertilized once in two to three years. Acid soils are limed at a rate of 0.5 to 1 kg/sq m, this treatment being sufficient for a period of five to ten years. The fertilizer rate per tree depending on its age can be calculated as follows. If, for example, a tree is six years old, the diameter of the ring around it is about 3 m (6:2) and its area is about 7 m². Assume that the fertilizer rate per sq. m of the ring around the tree is 4 kg of manure, 5 g N, 5 g P_2O_5, and 5 g K_2O. Then, the tree must be treated with 28 kg of manure and 35 g of each basic nutrient.

Treatment of the Fruit-Bearing Orchard

No row crops are grown in fruit-bearing orchards, and fertilizers are distributed evenly over the entire orchard area. In orchards, various systems of soil maintenance are usually employed: fallow (black fallow), establishment of sod (leaving the rings around trees bare), fallow combined with green manure cropping, sodding in combination with humification (grasses are cut several times within a season and left on the soil in the form of mulch), and mulching. In high-rainfall and irrigation farming areas, the soil is usually kept as black fallow for nearly a year after which annual grasses are grown for use as green manure over the entire area between rows or in every other row spacing. In low-rainfall regions, annual green manure grasses are sown in every other row spacing in alternation with black fallow (fallow for two years and annual grasses for a year).

Table 6.62. Fertilizer Rates for Orchards in Different Horticultural Zones (according to Spivakovsky)

Horticultural zone	Combination of inorganic fertilizers with organic ones	Manure of compost (t/ha)	Inorganic fertilizers (kg a.i./ha)		
			N	P_2O_5	K_2O
Northern, central, and southern (highr-ainfall and irrigation farming)	With manure	10-20	40-75	40-60	40-60
	Without manure, with green manure crops sown in summer	—	60-100	60-80	50-80
	With organic fertilizers being applied every other year and NPK in between	20-40	70-120	70-100	70-90
Southern (arid areas without irrigation)	With manure	20	30	30	30
	Without manure, with green manure crops sown in summer	--	40	40	30
	With organic fertilizers being applied every other year and NPK in between	30-40	60	60	40

Table 6.63. Tentative Annual Rates of Inorganic Fertilizers for Intensively Cultivated Orchards of the Moldavian SSR (kg a.i./ha)

Estimated yield (cent/ha)	N	Mobile phosphorus and potassium contents in the soil					
		low		medium		high	
		P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Pip fruit trees							
up to 100	90	45	90	30	60	—	45
100-200	120	60	120	45	90	30	60
200-300	180	90	150	60	120	45	90
300-400	210	—	--	90	150	60	120
above 400	240	—	—	120	180	90	150
Stone fruit trees							
up to 50	45	45	90	30	60	—	45
50-150	60	90	120	45	90	45	60
150-250	90	120	150	90	120	60	90
above 250	120	—	—	120	150	90	120

Average fertilizer rates for orchards in different horticultural zones are listed in Table 6.62.

Phosphorus and potassium fertilizers can be reserved in the soil for a period of two to four years. Here, applied on an annual basis are only nitrogen fertilizers. Organic fertilizers are used once in two to three years at rates ranging from 30 to 60 t/ha. After green manure has been incorporated, the manure rate is cut in half or no manuring is done at all in that year. Table 6.63 presents fertilizer rates for intensively cultivated orchards of Moldavia, as a function of yields and agrochemical properties of the soil. Reserve application of fertilizers in the soil before planting is not taken into account. If this has been done, the rates of phosphorus and potassium fertilizers must be reduced by 20 per cent.

The recommendations for fertilizer application in orchards need to be refined.

Fertilizer Application Schedules and Techniques in Orchards

Organic, phosphorus, and potassium fertilizers should preferably be applied in orchards in autumn when they are incorporated to a considerable depth. Nitrogen fertilizers are usually applied in spring. In low-rainfall regions, one third to one half of the annual rate may be applied in autumn. In this case, ammonia and amide fertilizers are preferable. In addition to basal application in autumn and in spring, dressing of fruit trees throughout the vegetation period is widely practised with preference being given to nitrogen fertilizers alone because phosphorus and potassium fertilizers incorporated to a shallow depth are not effective. The role of nitrogen dressing becomes especially important in irrigation horticulture. In low yield years, nitrogen fertilizers are applied only in spring before blooming. In high yield years, especially in orchards with winter varieties, two dressings are often performed, the first being done after blooming and the second, after shedding of unripe fruit. The nitrogen dressing rate is 30 to 50 kg/ha.

Also used for dressing may be manure water diluted with water two to three times and watered poultry manure (one part of manure for 10-20 parts of water). One square metre

receives 10 to 12 litres of the solution which is incorporated
into the soil.

The fertilizer incorporation techniques must be selected
with minimal root damage in view. Particular care must be
exercised in tilling the soil around stone fruit (cherry,
plum) trees and dwarf apple trees whose roots are near the
soil surface.

Conventional fertilizer ploughdown is done to the fol-
lowing depths: 10 to 15 cm around pip fruit trees or along
their rows, 5 to 10 cm around stone fruit trees or along their
rows, down to 20 cm between rows of pip fruit trees, and
down to 16 cm between rows of stone fruit trees. The soil
near tree tranks is tilled to a depth of 5 to 8 cm. However,
as far as orchards are concerned, the most effective procedure
is to incorporate fertilizers as deeply as possible into the
soil layer of the highest root density with as little damage to
the roots as possible. A few roots are always damaged when
the soil is tilled. Therefore, for such roots to resume normal
growth, the cutting should rather be done using a disc or
hanging cutter to the ploughing depth as opposed to roots
being torn off by the plough share. The standard practice in
young orchards is deep ploughdown of fertilizers around the
perimeter of the tree crown to cultivate the soil. In this
case, organic, phosphorus, and potassium fertilizers are
scattered along rows at the crown periphery in a strip 60 to
70 cm wide, then ploughed down to a depth of 30 cm and
even deeper. After two to four years, this procedure is re-
peated with the difference that the fertilizers are placed clos-
er to the middle between rows. Another common practice
in horticulture is placement of fertilizers in furrows cut
between rows to a depth of 25 to 30 cm. In young orchards,
the furrows are cut one to one and a half metres away from
the trunk. The older the trees, the farther from the trunk
the first furrow is cut. The furrow spacing between rows is
0.8 to 1 m. At the Uman Agricultural Institute, good results
were obtained in an experiment with mechanized deep incor-
poration of fertilizers under 20-year-old apple trees of the
Doneshta variety. Inorganic fertilizers were applied at the
rate $N_{120}P_{180}K_{180}$ using an orchard band applicator which
travelled parallel to tree rows at a distance of 3 m from the
trunk on either side and placed the fertilizer to a depth of

50 cm. Layered application was also successful at the Uman Institute. Here, fertilizers are placed on the bottom of a ploughed furrow in three runs of a three-bottom plough on either side of the row. Depending on the distance from the trunk, fertilizers are incorporated to different depths: 15 cm at a distance of 2 m from the trunk, 15 cm at a distance of 2 to 3 m, and 38 to 40 cm at a distance of more than 4 m. These depths are determined by the fact that tree roots lie deeper at farther distances from the trunk.

Inorganic fertilizers may be incorporated to a depth of 30 to 50 cm along tree rows in three lines using a PRVN-2,5A plough equipped with a fertilizer applicator. Liquid fertilizers are injected by hydroborers, vane borers, and injectors to a depth down to 50 cm around trees or along tree rows, as well as by intermittent-action hydraulic injectors to a depth of 40 cm in two lines along tree rows.

Deep incorporation of fertilizers prolongs their action one and half to two times as compared to conventional plough-down to a depth of 18 to 20 cm. When fertilizers are placed to a great depth, the total number of roots sharply increases, and especially, the density of branching roots in the soil layers that received fertilizers in the previous years; the frost resistance of trees also increases.

Foliar dressing is effective when trees start to bloom, at the fruit growth and fruit-bud formation stages. Trees should preferably be sprayed in the evening or in the morning and also on cloudy days for the solution to stay on leaves unevaporated as long as possible. If it rains six hours after spraying, it should be repeated. Apple trees are sprayed in spring with a 0.3% solution of urea, the concentration being increased to 0.4-0.5% in summer and in autumn. For pear trees, the concentration is reduced by one half. Cherry trees are treated with a 0.5-0.6% solution of urea in spring and a 1% solution in other seasons. To protect leaves against burns, 1.4 g of lime are added to 1 g of urea. Apart from urea, a 2-3 % solution of double superphosphate and a 1% solution of potassium sulphate are used for spraying. For foliar dressing of trees displaying no signs of micronutrient deficiency use is made of solutions of the following micronutrient fertilizers: zinc sulphate (0.1-0.5%) plus slaked lime (0.15%), boric acid (0.005-0.01%), and manganese

sulphate (0.1-0.5%). The spraying rate is 1000 to 1200 lit-
res/ha. When several micronutrient fertilizers are applied
jointly, the rate of each is cut in half (except for borax). The
best results are obtained when trees are sprayed with a mix-
ture of solutions of macro- and micronutrient fertilizers. The
number of dressings depends on the desired fruit yields.
For instance, high yields call for three to four dressings
throughout the vegetation period, while medium yields
necessitate two or three dressings.

Treatment of Palmette Orchards

In palmette orchards, the density of trees ranges from
660 to 1250 per hectare. Palmette horticulture in the USSR
is developed primarily in the southern regions. The predom-
inant species in such orchards is apple, pear being less com-
mon. Of the stone fruit species, peach is grown in this man-
ner. Fruit yields in palmette orchards are as high as 600 to
800 centners per hectare. Trees start bearing fruit in these
orchards three to five years after planting. Within the first
three to four years, young palmette orchards are treated only
with nitrogen fertilizers (the application rate increasing from
year to year from 45 to 90 kg/ha), provided the soil was
properly cultivated before and during planting. In the peri-
od from the fourth or fifth year after planting to the eighth
year, orchards with 400 to 600 trees per hectare are treated
once in two to four years with 30 to 40 t/ha of organic fertiliz-
ers and once a year with $N_{90-120}P_{45-60}K_{45-90}$ (depending on
the age of the trees and soil properties). In orchards with
800 to 1000 trees per hectare, the fertilizer rates are increased
by 25 to 30 per cent.

In fruit-bearing palmette orchards (400 to 600 trees per
hectare) more than eight years of age, organic fertilizers are
applied at a rate of 30 to 40 t/ha once in two to four years,
while inorganic fertilizers are applied yearly at the rate
$N_{120-180}P_{60-80}K_{60-120}$ depending on the horticultural zone.
At a tree density of 800 to 1000 per hectare, the rates are
increased by 25 to 30 per cent. In the organic fertilizer ap-
plication year, the rates of inorganic fertilizers are cut in
half.

Treatment of Bush-Fruit Gardens

Bush-fruit plantations are maintained for a rather long period of time; those of raspberry, currant, and gooseberry, for example, take anywhere from eight to ten years in crop rotation involving bush fruits. Bush-fruit gardens are treated with manure (compost) at an annual rate of 20 to 30 t/ha, the rate of mineral fertilizers being $N_{40-60}P_{40-60}K_{40-60}$. When 30 to 40 t/ha of organic fertilizers are applied, the rate of inorganic fertilizers the next year is $N_{50-90}P_{60-90}K_{40-90}$, no inorganic fertilizers being used in the same year with organic ones.

The Non-Black Earth Zone Research Institute of Horticulture recommends to place fertilizers in furrows. To this end, the soil between rows of currant and gooseberry bushes is inthrown once in three to four years. Manure and phosphorus-potassium fertilizers are placed in the furrows forming near the rows (25 to 30 cm deep). Then the fertilizers are covered with the soil by outthrowing. Besides, manure is also scattered once in three to four years at a rate of 3 to 4 kg per metre of a strip along the rows and is then incorporated into the soil.

Fertilizers are ploughed down between rows to a depth of 12 to 15 cm in the case of raspberry and 10 to 16 cm in the case of currant and gooseberry. The protective strips (to the outer projection of the crown) are tilled to a depth of 8 to 10 cm without damaging the roots. Phosphorus and potassium fertilizers may be reserved in the soil for a period of two to four years. Nitrogen fertilizers are applied each year. Organic, phosphorus, and potassium fertilizers are ploughed down in autumn and nitrogen fertilizers are incorporated by a cultivator in spring. Apart from being treated with nitrogen fertilizers in early spring, fruit bushes are also dressed at the fruit inception stage to produce a high yield. In bush-fruit gardens (especially raspberry ones), the soil between rows is mulched with peat, manure, and the like. In this case, fresh manure and peat-manure compost are slightly covered with earth to minimize ammonia nitrogen losses. The mulching rate is about 60 t/ha. When the soil under bushes is turned in autumn, the mulch is incorporated into it. Raspberry and currant are sensitive to chlorine, which is

why these crops should preferably be treated with potassium fertilizers with a lower chlorine content. However, when potassium chloride is applied in autumn, chlorine is leached out of the root layer of the soil and does not produce any harmful effect on the plants.

Foliar dressing is done with a 0.3-0.5% solution of urea, a 1-2% solution of potassium sulphate, a 2-3% solution of superphosphate, and a 0.02-0.05% solution of micronutrient fertilizers. In view of the fact that nutrients are taken up more vigorously from the solution through the lower side of the leaf, spraying must be aimed at that side.

Treatment of Strawberry

Strawberry is grown in special crop rotations over a period of four to five years, the most productive being the second and third years. Strawberry roots occupy mainly the 0-20 cm layer of the soil.

After strawberry is transplanted, the rows are mulched with manure or compost. After the soil has received sufficient amounts of organic and phosphorus-potassium fertilizers before transplanting, the plants can grow well without being treated within the first two to three years. Otherwise, organic and complete inorganic fertilizers have to be applied already in the second year. It is recommended to treat strawberry plantations with manure (or compost) at a rate of 30 to 40 t/ha and with $N_{40-70}P_{50-60}K_{40-60}$. Manure, phosphorus and potassium fertilizers are incorporated into the soil in autumn. The soil between rows is tilled to a depth of 8 to 10 cm and in rows, to a depth of 4 to 6 cm. Nitrogen fertilizers are usually applied twice: in early spring (20-40 kg N/ha) and after harvesting (30-40 kg N/ha). Whether dressing with nitrogen is necessary is judged from the leaf colour or suggested by chemical leaf diagnosis data. Foliar dressing with a 0.4% solution of urea increases fruit yields by 20 to 30 per cent. The plants are sprayed at the blooming and fruit inception stages. The concentration of the micronutrient fertilizer solution used for dressing is 0.02 per cent.

Table 6.64 illustrates the fertilizer system adopted at the Lenin State Farm in the Moscow Region for crop rotation involving strawberry grown on soddy podsolic moderately

Table 6.64. Fertilizer System for Nine-Course Crop Rotation Involving Strawberry at the Lenin State Farm (according to Kuznetsova)

Crop rotation course	Crop	Fertilizer rate per hectare
1	Winter grain crops	Compost, 20-30 t; lime, 2-2.5 t; $N_{70-80}P_{60-70}K_{150-180}$
2	Grain oat	N_{70-80} as basal fertilizer and P_{15-20} as starter row fertilizer
3	Annual grasses grown for use as green manure	Manure, compost, 20-30 t; $N_{70-80}P_{70-80}K_{120-150}$
4	Annual grasses grown for use as fodder	Compost, 30-40 t; $P_{180-200}$ N_{80-90} P_{50-70} $K_{120-150}$ Pretransplanting application: compost, 35-40 t, P_{70-80} $K_{200-240}$
5	Young strawberry	N_{35-50}
6	Strawberry of 1st-year fruitage	No treatment
7	Strawberry of 2nd-year fruitage	N as required
8-9	Strawberry of 3rd- and 4th-year fruitage	$N_{35-50}P_{30-40}K_{90-120}$

loamy soils. The average fruit yields in 1972, 1973, and 1975 at this farm were 60.6, 58.7, and 113.3 cent/ha, respectively, the mean annual return from one hectare of strawberry plantation being 6533 rubles.

6.9.5 Treatment of Vegetable Crops Grown in Hothouses

The yield of crops grown in hothouses is several times higher per unit area than that of open-ground crops, which is a decisive factor in prescribing an appropriate fertilizer system. Fertilizers in hothouses are applied at higher rates (anywhere from 6 to 21 t/ha of inorganic fertilizers), and most of the nutrients have to be supplied throughout the vegetation period in order not to increase the soil solution concentration by the initial high rate of the basal fertilizer. In intensive hothouse vegetable growing, agrochemical moni-

toring of the soil and plants is carried out on a monthly basis throughout the vegetation period.

One centner of cucumbers, tomatoes, and lettuce removes the following amounts of nutrients (kg):

	N	P_2O_5	K_2O	CaO	MgO
Cucumbers of the Marfinsky variety	0.25	0.13	0.51	0.07	0.03
Parthenocarpic cucumbers	0.14	0.09	0.28	0.17	0.03
Tomatoes	0.33	0.12	0.63	0.46	0.08
Lettuce	0.23	0.07	0.40	0.10	0.03

The factors of nutrient utilization by hothouse vegetable crops are as follows: 15 to 20 per cent for mobile phosphorus (according to Truog), 30 to 40 per cent for mobile potassium (according to Maslova), and 100 per cent for water-soluble forms of nutrients (water extract). The inorganic fertilizer nutrient utilization factors are 50 to 70 per cent for nitrogen, 20 to 40 per cent for phosphorus, 60 to 70 per cent for potassium, and 60 to 70 per cent for magnesium.

A major factor of high vegetable yields in hothouses is the soil used there.

Composition and Properties of Hothouse Soils

In hothouses where vegetables are grown directly on the ground, the soil bed is 25 to 30 cm thick. One square metre of the hothouse floor space must bear at least 0.20 to 0.25 m^3 of soil. In modern hothouse market gardening, it has become standard practice to use the same soil over a period of, say, 15 to 25 years, provided it undergoes sterilization (steaming, gas and wet disinfection) and demineralization (washing if there is a drainage system). Hothouse soils vary widely in composition. As an example, consider the following soil compositions: (1) low peat (75%) + vegetable earth (25%); (2) low peat (60%) + vegetable earth (20%) + + manure (20%); (3) low peat (100%); (4) low peat (40%) + + garden or field soil (40%) + horse manure (half mixed with sawdust) (20%); (5) low peat (40%) + high or transitional peat (20%) + vegetable earth or field soil (10%) + + manure (25%) + coarse sand (5%).

In areas where there is no peat, the hothouse soil is prepared from a mixture of topsoil with humus, manure, or compost with sawdust, shreddings, rice husk, or tree bark being

added to keep the soil loose. Hothouses located near logging or wood enterprises use composted (1.5- to 3-year-old compost) or fresh, uncomposted bark, alone or mixed with 25 to 75 per cent peat, as a cheap and effective substrate. Bark promotes the development of plant roots, contains phosphorus, potassium, magnesium, and micronutrients, but is virtually free of nitrogen. Added to one cubic metre of composted bark are 4.3 kg of urea and 1.5 kg of double (or 3 kg of ordinary) superphosphate. Low, transitional, or high peat without admixtures may also be used as hothouse soil.

Vegetables are also grown in hothouses on straw bales. The straw must be fresh and not treated with herbicides. It is compressed into bales $0.5 \times 0.5 \times 1$ m in size. The straw requirements of hothouses are 9300 bales or 120 to 130 tons per hectare.

To improve the hydrophysical properties of soils, polymers (kriliums) are incorporated into it by sprinkling to a depth of 15 to 20 cm at a rate of 0.1 to 0.5 per cent of the soil weight, then intimately mixed with the soil throughout the bed thickness.

To prepare hothouse soils it is recommended to use low peat with a normal ash content (about 12%) and the following characteristics: degree of decomposition, 40% max.; water capacity, 500-1000%; degree of base saturation, 65%; mean exchange capacity, 137 meq; exchangeable aluminium content, 0.3 meq per 100 g of absolutely dry peat; N content, 1.6-2.6%; P_2O_5 content, 0.05-0.40%; K_2O content, 0.03-0.20%; CaO content, 1.5-3.0%; and Fe_2O_3 content, 0.20-3.00% (all the nutrient contents are given for absolutely dry peat). It is not recommended to use calcareous and vivianite peats as well as peats with high boron content. Peat should not contain more than 5 to 6 per cent of total iron and more than one per cent of mobile iron. To neutralize the acidity of the ton of absolutely dry peat requires the following amounts of lime (in kg) depending on pH_{KCl} : 60 to 30 at pH 3.6-4.8, 30 to 10 at pH 4.8-5.8, and 10 to 5 at pH 5.8-6.3.

The optimal reaction of hothouse soils must be close to neutral, the pH of the water extract being 6.5 to 6.8. The lime rate for hothouse soils is determined from the salt extract pH or from one half of the hydrolytic acidity. Accord-

ing to the organic matter content, hothouse soils fall under the following classification: low—30%, medium—30-60%, and high—exceeding 60%. The limiting salt concentration in the hothouse soil depends on its organic matter content and is determined from the formula $L = \dfrac{C \cdot 2 + 15}{100}$, where L is the limiting salt concentration (%) and C is the organic matter content determined by the ignition method (%).

The limiting chlorine content in the soil must not exceed 0.024 per cent in tomato cultivation and 0.007 per cent in cucumber cultivation (in terms of absolutely dry soil). Application of 100 g of potassium chloride per square metre (or 10 cent/ha) makes the chlorine concentration in the soil exceed the tolerable level. Ordinary superphosphate is also toxic to plants when present in excess amounts because of the high content of gypsum and salts of heavy metals in it. Plants (especially young ones) may also be poisoned with ammonia and hydrogen sulphide as a result of heavy application of slightly decomposed manure to waterlogged soil. In hothouse soils, the content of some nutrients per kg of absolutely dry soil should not exceed the following limits: boron, 1 mg (water extract); manganese, 300 mg ($0.1N$ H_2SO_4); copper, 8 mg ($0.1N$ HCl); zinc and cobalt, 6 mg each ($0.1N$ HNO_3); and molybdenum, 0.5 mg (according to Grieg).

Hothouse soils are prepared either in situ, when the hothouse is put into operation, or in advance, by composting. Such compost is ready in six to eight months. For purposes of biothermal disinfection, manure is stacked separately for a period of two to three months.

In recent years, the results of analysing water extracts of hothouse soils have been used extensively. The optimal content of mobile nutrients in the hothouse soil (water extract) is determined from the following formulas, with due account for the organic matter content in it:

$$N = \frac{C \cdot 2 + 15}{3} ; \quad K_2O = \frac{C \cdot 2 + 15}{1.5} ; \quad MgO = \frac{C \cdot 2 + 15}{5} \cdot 1.66$$

where N, K_2O, and MgO stand for the contents of respective nutrients (mg per 100 g of absolutely dry soil), and C is the organic matter content (ignition loss) (%).

Proceeding from the calculated optimal level (L), one can arrive at the following classification of soils in terms of the

mobile nutrient contents in them: low—$1/3L$, below normal —$1/3$-$2/3L$, normal—$2/3$-$1L$, above normal—1-$1\frac{1}{3}L$, and high—in excess of $1\frac{1}{3}L$. In terms of phosphorus content, soils are classified irrespective of the amount of organic matter they contain (mg P_2O_5 per 100 g of absolutely dry soil): low—up to 2; below normal—2-4; normal—4-6; above normal—6-8; high—exceeding 8. The actual nutrient content in the soil for comparison with the above calculation-based classification is determined in a water extract with a water-to-soil ratio of 1:5 or 1:10 in the case of peat.

At present, at some hothouse farms, the content of water-soluble nutrients in the soil is determined by the volumetric extraction method (in mg per litre of moist soil), the substrate-to-water ratio being 1:2. The total salt concentration is found in the same extract (Table 6.65) potentiometrically (mS/cm) or by the dry residue method (in g per litre of soil).

Table 6.65. Classification of Hothouse Soils for Tomato and Cucumber Growing, Based on the Water-Soluble Nutrient and Salt Contents As Determined by the Volumetric Extraction Method (recommendations of the Research Institute of Vegetable Growing)

Nutrient and salt supply	Nutrient content (mg/litre)				Total salt content	
	N	P_2O_5	K_2O	MgO	mS/cm	g/litre
Low	< 40	< 10	< 60	< 30	< 0.5	< 0.8
Medium	40-80	10-25	60-130	30-80	0.5-1.0	0.8-1.5
Normal	80-130	25-35	130-200	80-120	1.0-2.0	1.5-3.0
Above normal	130-170	35-45	200-240	120-170	2.0-3.0	3.0-4.0
High	> 170	> 45	> 240	> 170	3.0-4.0	4.0-5.0

Note. To convert the nutrient contents to g/m² at a soil bed thickness of 30 cm, multiply the tabulated values by 0.3.

For the hothouse soil to be used continuously as long as possible, the irrigation water must meet certain requirements. Its pH must range from 6 to 7, one litre of such water must contain no more than 350 mg Ca, 150 mg Cl, 180 mg Na_2O,

350 mg SO_4^{2-}, 1 mg Fe, and 0.6 mg F; no phenol must be present, and the dry residue must be in the range of 1000 to 1200 mg per litre.

Nutrient Mixtures for Seedling Pots

Vegetable seedlings may be grown in pots made of polymer materials or high peat and filled with a nutrient mixture, in peat or peat-compost blocks produced by presses, and in fabricated peat blocks.

The mixtures for seedling pots may be of the following compositions:

(1) decayed low peat (60%) + humus (20%) + field soil or vegetable earth (10%) + cow manure (5%) and sawdust (5%);

(2) decayed low peat (60%) + field soil or vegetable earth (13%) + horse manure (20%) and cow manure (7%);

(3) decayed low peat (70%) + cow manure (7%) and sawdust (23%);

(4) high peat (90%) + cow manure (10%);

(5) humus (50%) + field soil or vegetable earth (40%) and sawdust (10%);

(6) humus (45%) + cow manure (10%) + sawdust or rice husk (45%).

The following quantities of nutrients in the form of inorganic fertilizers are added to one cubic metre of the potting mixture (kg):

Crop	N	P_2O_5	K_2O
Cabbage	0.5-0.7	0.4-0.5	0.4-0.5
Tomato, pepper, eggplant	0.4-0.5	0.6-0.8	0.6-0.9
Cucumber, watermelon, melon	0.3	0.2.0.3	0.3-0.5

The lime rates (in kg) per cubic metre of the mixture are determined from the salt extract pH: 6 at pH 4.5-5.0, 5 at pH 5.1-5.5, 2 to 3 at pH 5.5-6.5, and 0.5 at pH 6.5-7.2.

When pure transitional or low peat blocks (8 × 8 × 8 or 10 × 10 × 10 cm) are made, added to one cubic metre of the peaty matter are up to 6.5 kg of dolomitic meal, 0.5 kg of ammonium nitrate, 1 kg of potassium nitrate, 1.5 kg of double superphosphate, 0.3 kg of magnesium sulphate, 3 g amounts of copper sulphate, zinc sulphate, boric acid, and co-

balt nitrate, 6 g of ammonium molybdate, and 11 g of manganic sulphate. The nutrient rates per cubic metre of peat are 0.30 kg N, 0.65 kg P_2O_5, 0.45 kg K_2O, and 0.1 kg MgO.

Blocks fabricated from high peat with addition of complete fertilizer and micronutrients (copper, boron, molybdenum, zinc, cobalt, and iron) permit seedlings to be produced on a commercial basis. Each block contains 30 cells, sized, each, $10 \times 10 \times 4$ cm. To one cubic metre of the peaty matter used in the fabrication of blocks about the same amount of macro- and micronutrients is added as in local production of peat blocks by compression.

Treatment of Vegetable Crop Seedlings

Cabbage Seedlings. The seedlings of early cabbage and cauliflower are grown in cold frames or hotbeds and in hothouses covered with plastic film, those of late cabbage varieties are grown in both plastic films hotbeds and hothouses as well as in cold frames, and the seedlings of medium varieties are grown in cold beds in the open or in plastic film-screened shade houses. The seedlings of early cabbage and cauliflower are forced in peat-compost blocks or without them.

One hectare of cold bed or frame soil receives 100 to 200 tons of manure or compost, phosphorus-potassium fertilizers, at the rate $P_{40-80}K_{60-120}$, and lime as required during autumn ploughing, while in spring it receives about 50 kg N. The seedlings are usually dressed twice: at the stage of two true leaves and six to ten days after the first dressing. The first dressing involves 20 g of ammonium nitrate, 30 g of superphosphate, and 8 g of potassium chloride per 10 litres of water, while the second dressing is performed at a rate of 30 to 40 g of ammonium nitrate, 40 g of superphosphate, and 20 g of potassium chloride per 10 litres of water. One square metre is treated with ten litres of the solution.

Early and late cabbage as well as cauliflower, grown in peat-compost blocks, are dressed once or twice at a rate of 20 to 40 g of ammonium nitrate, 20 to 40 g of superphosphate, and 8 to 20 g of potassium chloride per 10 litres of water. It takes ten litres of the solution to treat two to three square metres. Cauliflower seedlings are also subjected to two fo-

liar dressings: with a 0.02% solution of boric acid and a 0.05% solution of ammonium molybdate at the stages of the second and third, then fifth and sixth leaves (before being transplanted into the open ground).

Cucumber and Tomato Seedlings. The seedlings of these two crops are grown in peat-compost blocks. Cucumber seedlings are not dressed as a rule, whereas those of tomato are dressed once or twice. The first dressing is done ten to twelve days after pricking out at a rate of 5 g of ammonium nitrate, 40 g of superphosphate, and 15 g of potassium chloride per 10 litres of water with ten litres of the solution being applied to three square metres. The second time the seedlings are dressed two weeks before they are transplanted into the open ground at a rate of 10 g of ammonium nitrate, 60 g of superphosphate, and 20 g of potassium chloride per 10 litres of water. This amount of the solution is used to treat 1.5 to 2 m².

When cucumber and tomato seedlings are grown in boxes filled with high peat, one cubic metre of the latter is treated with 12 to 14 kg of dolomitic meal, 600 g of ammonium nitrate, 800 g of double superphosphate, 800 g of potassium sulphate, 15 g of boric acid, 15 g of ferric sulphate, 20 g of blue vitriol, 2 g of manganic sulphate, 4 g of ammonium molybdate, and 2 g of zinc sulphate. Eight to ten days after pricking out, the seedlings are dressed with a solution of 15 g of potassium nitrate, 5 g of ammonium nitrate, 5 g of urea, 10 g of double superphosphate, 5 g of potassium sulphate, and 5 g of magnesium sulphate in 10 litres of water. Ten litres of such a solution are used to treat two square metres. After dressing, the plants are watered to wash off the solution from their leaves.

Treatment of Cucumbers, Tomatoes, and Lettuce

Soil Culture. 10 to 15 days before cucumber or tomato seedlings are transplanted into the soil, it receives 15 to 25 kg of manure per square metre, then a soil sample is taken for analysis. The sample is analysed for the organic matter content by the ignition method, the iron and manganese contents in a Morgan extract, ammonia and nitrate nitrogen, phosphorus, potassium, and calcium in a water extract, the

total salt concentration, and pH. The analytical results are compared with the calculated values (using the above-presented formulas) of nutrient contents in the hothouse soil to determine inorganic fertilizer rates from Table 6.66 for basal application. After basal application at the established rate, soil samples are taken once more for analysis to determine the total salt content which is then compared with the calculated maximum permissible salt concentration. If the salt concentration exceeds the maximum, the soil is watered lavishly. No dressing is performed within the first four to six weeks after transplantation of the seedlings. Afterwards, the rates of inorganic fertilizers used for dressing are also determined from Table 6.66 proceeding from the results

Table 6.66. Inorganic Fertilizer Rates for Basal Application to Cucumbers and Tomatoes and Their Dressing (g a.i./m²) (recommendations of the Research Institute of Vegetable Growing)

Nutrient contents in the soil (calculated)	Cucumbers				Tomatoes			
	N	P_2O_5	K_2O	MgO	N	P_2O_5	K_2O	MgO
Low	17-25	45-60	26-39	8-12	25-32	45-60	78-100	25-40
Below normal	8-17	23-45	13-26	5-8	19-25	23-45	57-78	15-25
Normal	0-8	0-23	0-13	0-5	13-19	0-23	39-57	10-15
Above normal	—	—	—	—	6-13	—	18-39	5-10
High	—	—	—	—	0-6	—	0-18	0-5

Note. To convert the above rates into kg/ha multiply them by 10.

of monthly agrochemical analyses of the soil and leaves. However, as opposed to the basal fertilizer, the dressing is carried out in a split manner several times with no more than 5 g N and 10 to 15 g K_2O being applied at once per square metre for root dressing (dry or with water), and the dressing at the same rate is repeated 7 to 15 days later. In terms of physical fertilizer, the overall rate of a single dressing should not exceed 70 g/m² (especially for cucumbers) lest the soil solution concentration increases, including a maximum of 15 g of ammonium nitrate and 30 g of potassium sulphate. Cucumbers and tomatoes are usually dressed five to eight times within the vegetation period. Dressing is more effective

in sunny weather. Used for dressing are primarily nitrogen and potassium for they are leached out of the root layer as a result of frequent watering and also because of the possible high salt concentration in the soil as a consequence of heavy bulk application of nitrogen and potassium fertilizers before the seedlings are transplanted.

Root dressing is followed by foliar one whereby solutions of inorganic and micronutrient fertilizers are sprayed. The solution concentration must not exceed 0.22 to 0.27 per cent for cucumbers and 0.40 per cent for tomatoes. To dress cucumbers, up to 20 g of urea or 5 to 7 g of ammonium nitrate, 5 to 6 g of double superphosphate, and 7 to 8 g of potassium sulphate (or chloride) are dissolved in 10 litres of water. A stock solution is prepared from micronutrient fertilizers: 2.86 g of boric acid, 0.08 g of blue vitriol, 0.1 g of ammonium molybdate, and 1.8 g of manganic sulphate per litre of water. Ten litres of the inorganic fertilizer solution prepared for spraying are thoroughly mixed with 10 ml of the stock solution of micronutrient fertilizers. 25 to 30 litres of such a solution are needed to treat 100 square metres of the hothouse soil. Foliar dressings must be performed on cloudy days. Of great importance is dressing with carbonic acid (2 to 2.5 kg of food-grade carbonic acid per 100 m²). The best time for carbonic acid dressing is in the morning.

The inorganic fertilizer rates given in Table 6.66 depend on the calculated optimal content of a particular nutrient in the hothouse soil. This optimal level, in turn, depends on the organic matter content. The more organic matter the soil contains, the higher the calculated optimal nutrient (except for phosphorus) content in it. As a result, the same value of actual content of a nutrient in the soil (from agrochemical analysis data) will correspond to a lower calculated content and, consequently, the fertilizer rate will increase. This fertilizer rate determination method is deficient in that no account is taken of the estimated yielding capacity of the vegetable crops.

In recent years, wider recognition has been gained in hothouse gardening by an inorganic fertilizer rate determination method taking into account the removal of nutrients, the factors of their utilization from the soil, and fertilizers.

At the "Moskovsky" state farm, where hothouse soils are

prepared from a mixture of peat, vegetable earth, and manure and contain 10 to 40 per cent organic matter, have a density of 0.3 to 0.8 g/cm³ and a total porosity of 60 to 90 per cent, one square metre of the soil receives during basal application 10 to 12 kg of organic fertilizers which are then ploughed down, a soil sample is taken for analysis of the water extract (by the volumetric extraction method), and the nutrient rates for basal application are determined using a table. The nutrient requirements for dressing are defined as the difference between the calculated rate for the estimated yield and the basal application rate. The first dressing of cucumbers is carried out four weeks, and that of tomatoes six to eight weeks, after transplantation of the seedlings. The intervals between the subsequent dressings are as indicated above. In this case, soils and leaves are analysed agrochemically every month for nutritive diagnosis. The rate of one dressing should not exceed 5 g N and 10 to 15 g K_2O per square metre, the total amount of nutrients received throughout the vegetation period during root and foliar dressings being 30 to 35 g N and 55 to 60 g K_2O per square metre for cucumbers and 20 to 22 g N and 15 to 20 g K_2O for tomatoes.

Example. The estimated cucumber yield from a square metre is 30 kg, the nutrient removal being 43 g N, 27 g P_2O_5, 84 g K_2O, and 9 g MgO. With the soil containing (water extract) 60 mg N, 20 mg P_2O_5, 100 mg K_2O, and 40 mg MgO per litre (dm³) of fresh soil, the water-soluble nutrient contents per square metre at a soil bed thickness of 30 cm (i.e. in 0.3 m³) will be: 18 g N, 6 g P_2O_5, 30 g K_2O, and 12 g MgO (the initial values have been multiplied by 0.3).

The same amounts of nutrients may be taken up by plants from the soil since the water-soluble nutrient utilization factor is taken equal to 100 per cent. Hence, the plants additionally require 24 g N, 21 g P_2O_5, and 54 g K_2O. Cucumbers take up from inorganic fertilizers about 60% N, 30% P_2O_5, and 70% K_2O. Then, taking into account the utilization factor, the plants must receive from inorganic fertilizers 40 g N, 70 g P_2O_5, and 77 g K_2O. According to Table 6.67, one square metre of the soil with its moderate nutrient content in this case must receive from the basal fertilizer 15 g N, 35 g P_2O_5, and 35 g K_2O. It then remains to supply by dressing 25 g N, 35 g P_2O_5, and 42 g K_2O. This can be achieved

by four to five dressings in view of the fact that no more than 5 g N and 10 to 15 g K_2O can be supplied per dressing. Phosphorus in the form of double superphosphate could be supplied with the basal fertilizer or via one or two dressings at a rate of 10 to 15 g P_2O_5 or 25 to 35 g of double superphosphate per square metre so that the total amount of all fertilizers applied per dressing does not exceed 70 g/m^2.

The best fertilizers for hothouse culture include ammonium nitrate, urea, double superphosphate, potassium sulphate, potassium nitrate, ammonium-magnesium phosphate, potassium metaphosphate, and dolomitic meal.

Table 6.67. Inorganic Fertilizer Rates for Basal Application to Vegetable Crops (g a.i./m^2) Depending on the Nutrient Content in the Hothouse Soil. Determined in a Water Extract by the Volumetric Extraction Method (recommendation of the Research Institute of Vegetable Growing)

Nutrient content in the soil	N	P_2O_5	K_2O	CaO	MgO
Cucumbers					
Low	20-30	45-60	45-60	20-30	15-20
Moderate	10-20	25-45	30-45	10-20	10-15
Normal	0-10	0-25	0-30	0-10	0-10
Above normal	--	—	—	—	—
Tomatoes					
Low	12-25	45-60	75 100	30-35	35-45
Moderate	0-12	25-45	50-75	20-30	30-35
Normal	--	0-25	25-50	15-20	20-30
Above normal	—	—	0-25	10-15	10-20
Lettuce					
Low	20-26	30-45	10-20	15-25	15-20
Moderate	10-20	20-30	0-10	10-15	10-15
Normal	0-10	0-20	--	0-10	0-10
Above normal	--	---	—	—	--

Straw Bale Culture. This type of culture involves cucumbers and tomatoes. Bales arranged in a hothouse are treated with hot water (60-70 °C). Watering is repeated in two days. One kilogram of straw must be treated with 1.3 to 1.5 litres of water each time. As a result, the straw swells and bet-

ter retains the inorganic fertilizers applied two days after
the second watering. They are spread uniformly at a rate of
1.4 kg of ammonium nitrate, 1.2 kg of ordinary superphos-
phate (or 0.6 kg of double superphosphate), 1.3 kg of potassium
nitrate, 0.45 kg of magnesium sulphate, and 34 g of ferric
sulphate per 100 kg of straw. The fertilizers are then intro-
duced into straw bales with water poured from a can with a fine
mesh. If the fertilizers remain in the uppermost layer of the
bale in a high concentration, the roots of young plants may
be damaged. Lime is applied after inorganic fertilizers (370-
400 g per 100 kg of straw). One or two days before seedlings
are transplanted, a soil layer 8 to 10 cm thick is placed on
the straw bales. Sometimes, instead of being spread over
the entire surface, the soil is placed only in holes prepared
for transplantation. The seedlings are transplanted in 12 to 16
days as a rule. The soil layer between the seedling pot and
the straw bale must be at least 5 to 6 cm thick. The first dress-
ing is performed two weeks after transplantation with 7.5 g
of ammonium nitrate and the same amount of potassium ni-
trate being dissolved in 10 litres of water. All the subsequent
dressings are carried out at 7- to 10-day intervals. Here, only
nitrogen and potassium fertilizers are used. All the phos-
phorus is applied before transplantation. The overall fertiliz-
er rate per dressing must not exceed 70 g/m². Foliar dress-
ing is performed exactly in the same manner as in other
types of culture.

Hydroponic Culture. The substrate used in hydroponic cul-
ture of vegetables is granite gravel, claydite, and vermiculite
(pure or mixed with gravel). The particle size ranges from
3 to 15 mm. The most commonly used nutrient solutions in
cultivation of cucumbers and tomatoes are Chesnokov's
and Bazyrina's solutions with 200 g of ammonium nitrate,
500 g of potassium nitrate, 550 g of ordinary superphos-
phate, 300 g of magnesium sulphate, 6 g of ferrous chloride,
0.72 g of boric acid, 0.02 of copper sulphate, 0.45 g of man-
ganic sulphate, and 0.06 g of zinc sulphate being dissolved
in 1000 litres of water. This nutrient solution allows up to
20 kg of tomatoes and up to 40 kg of cucumbers to be har-
vested from one square metre of useful area.

Some hothouse farms use other solutions whose composi-
tion depends on cucumber and tomato growth stages, their

pH being 6.5-6.7 for cucumbers and 6.0-6.2 for tomatoes. The solution is partially replenished within a month, then completely replaced after the substrate is washed with water for a day or two. The solution is adjusted every five days with the deficient nutrients being added as required.

Once a year, 20 days before seedlings of a new crop are transplanted, the substrate is disinfected with a 5% formalin solution for 24 hours or a 2% solution of carbathion for 6 hours, then flushed with water for the odour to disappear completely. It is also possible to sterilize the substrate with steam (100 °C) for two to three hours. In the course of time, the substrate (especially claydite) tends to accumulate various salts, root exudates toxic to plants, and harmful fungi. This is why apart from being disinfected the substrate has to be recycled using water (in the case of granite gravel) or various chemical solutions. The most suitable recycling solution for claydite is potassium hydroxide which binds silicic acid into water-soluble potassium metasilicate. Two to three days after potassium hydroxide is applied to the substrate, it is removed using a formalin solution which, in turn, is removed with water and a superphosphate solution (50 g per square metre of substrate).

High Peat Culture. In this type of culture, the same solutions are used as in hydroponic culture. Wide recognition has been gained by Abele's solution whose composition is varied according to plant development stages and is as follows (g per 1000 litres of water): ammonium nitrate, 180 to 300; potassium nitrate, 290 to 1100; superphosphate, 280 to 800; magnesium sulphate, 250 to 300. To grow tomatoes use is also made of the nutrient solution developed at the Timiryazev Agricultural Academy in Moscow, containing 2.8 to 2.9 kg of ammonium nitrate, 3.3 to 4.9 kg of superphosphate, 5.9 to 6.8 kg of potassium nitrate, and 1.9 to 2.9 kg of magnesium sulphate per 1000 litres of water. This solution is applied once a month, water being used the rest of the time.

In a combined procedure, dry fertilizers are incorporated into high peat before transplantation, then the plants are watered for two to three months, and only after that Abele's solution is used. A prerequisite for high vegetable yields in high peat culture is application of micronutrient fertilizers at the following rates: 13.8 g of borax, 41.4 g of ferric che-

late, 41.4 g of ferric sulphate, 25.2 g of copper sulphate, 16.8 g of zinc sulphate, 16.8 g of manganic sulphate, and 2.8 g of sodium molybdate per cubic metre of peat.

6.10 Mechanized Storage, Handling, and Application of Inorganic Fertilizers

Inorganic fertilizers are transported by rail or river from chemical plants, reloaded into the storage facilities at railway stations or piers belonging to the district association "Selkhozkhimiya", and then hauled to farms. About 80 per cent of fertilizers are transported in bulk, the rest being packaged. In the latter case, fertilizers are sealed in waterproof paper, PVC, or polyethylene bags holding anywhere from 30 to 60 kg and bearing labels which indicate the number of the appropriate state standard, fertilizer type, and manufacturer's name. Handling of bagged fertilizers is most convenient when bags are arranged in several rows on racks or trays. A promising way to transport inorganic fertilizers is in self-unloading padded containers. Finely powdered fertilizers (pulverized limestone and phosphate rock) should preferably be transported in tank cars with pneumatic unloading.

Railway storehouses are built to hold 1.2 to 15 thousand tons of fertilizer. Special storage facilities with a capacity of 1200 to 3500 tons are built for ammonium nitrate which calls for special storage conditions in view of its inflammability and explosivity.

Liquid fertilizers are carried in ammonia tanks and stored in upright or horizontal metal tanks with a total capacity of 600 to 2000 m³.

When ammonium nitrate is stored on racks, the stack may be up to 4.4 m high, while on trays bags containing this fertilizer are arranged in two layers. If no racks or trays are available, ammonium nitrate bags are stacked to a height of 1.5 to 1.8 m in 8 to 10 rows. The weight of a stack should not exceed 120 tons. All other bagged fertilizers should also be stored on racks arranged in four rows to a total height of 4.4 m. Unbagged fertilizers may be kept in heaps up to 5 m high. It is convenient to store pulver-

ized phosphate rock and limestone, and also pelletized superphosphate, in silos.

Railway storehouses are equipped with machines loosening unbagged fertilizers as they are being unloaded from cars or from the storehouse, and belt conveyors are employed to transfer them into the storehouse or trucks. Bagged fertilizers are reloaded from cars into the storehouse or from the latter into trucks with the aid of electric or truck loaders. Pulverized fertilizers are reloaded from tank and box cars into silos, bins, or tank trucks with pneumatic loaders.

The underground storage facilities or storehouses at chemicalization stations are provided with loading tractor bulldozers, multipurpose front-end tractor loaders equipped with replaceable loading attachments, and loading excavators to handle inorganic fertilizers.

To prepare inorganic fertilizers for application use is made of debaggers, shredders, and special mixing and metering devices.

Farms often use binary or ternary mixtures of inorganic fertilizers. The prepared fertilizer mixture must lend itself readily to broadcasting and be homogeneous in composition to avoid irregular (in excess of 15-20%) spreading over the field, especially by centrifugal broadcasters. When various mixtures are prepared, the moisture content must not exceed 0.3 per cent in ammonium nitrate, ammonium sulphate, and urea, 2 per cent in ground phosphate rock and potassium fertilizers, and 5 per cent in pelletized double superphosphate. Granulated or pelletized fertilizers are usually mixed at farms. Potassium fertilizers can be mixed with ground phosphate rock well in advance, while mixing them with superphosphate is preferable shortly before application.

It should be borne in mind that mixing ammonium nitrate with superphosphate and adding ammonium nitrate and urea to the mixture, as well as urea and superphosphate, yield a hygroscopic sticky mass difficult to broadcast.

Depending on how far fields are from storage facilities and what machinery is available, the following fertilizer transportation and application schemes are used:

(a) direct: railway storehouse—broadcaster—field;

(b) reloading: railway storehouse—reloading machinery—broadcaster—field;

(c) transit: railway storehouse—tractors and trucks—storage facilities of the interfarm chemicalization station and underground storage or temporary storage in the field.

Then, if fertilizers have been stored in the field, they are spread by tractor-mounted broadcasters or, if they have been kept in underground storage, by truck-mounted ones.

Fertilizers may also be hauled from the underground store in reloading trucks to the broadcaster in the field. In the latter case, we are dealing with what may be termed as reloading-transit scheme.

If the field is 3 to 5 km distant from the storehouse, tractor-mounted broadcasters are normally used in the direct scheme; at longer distances, 5 to 8 km, truck-mounted broadcasters are employed.

The economically efficient range of aerial application is about 10 to 12 km from the airfield with fertilizers being sprayed at a rate of 100 to 200 kg per hectare.

6.11 Economical Effectiveness of Fertilizer Application

According to the results of field experiments, application of one kilogram of the active ingredient (in a ternary or binary combination of nitrogen, phosphorus, and potassium) increases the yield of winter and spring crop grain by 2.7 to 5.7 kg, maize grain by 4.7 to 7.1 kg, rice grain by 6 to 11 kg, potatoes by 20 to 32 kg, sugar beet by 26 to 52 kg, raw cotton by 2.3 to 5.6 kg, flax straw by 4.6 to 6.1 kg, and sunflower seeds by 2 to 3.5 kg. Depending on the crop as well as soil and climatic conditions, the net return from one ruble spent in application of inorganic fertilizers ranges, according to the experimental data supplied by the Soviet agrochemical service, from 1.5 to 8 rubles, averaging 3 to 4 rubles. One ruble spent in application of organic fertilizers returns 1.5 to 5 rubles, and that spent in liming returns 3 to 7 rubles.

Under actual farming conditions, the economic effectiveness of fertilizer application to an individual crop or in

crop rotation is determined by comparing yields on treated and untreated (control) plots. If no control plots are involved, use is made of data supplied by the experimental stations where yield increases under similar conditions are studied. The cost of products is expressed in nominal or actual purchase prices. The net return from fertilizer application is determined from the formula:

$$NR = (MP + BP) - E$$

where NR is the net return (rubles), MP is the cost of the main product increment due to fertilizer (rubles), BP is the cost of the by-product increment due to fertilizer (rubles), and E stands for the overall expenses involved in fertilizer application (rubles).

The overall expenses (E) represent a sum of the following components:

$$E = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7$$

where E_1 is the wholesale price of fertilizers (for inorganic fertilizers, lime, and peat) or price estimate (for local organic fertilizers), E_2 is the expense involved in hauling fertilizers to the farm and field (with established transportation charges taken into account), E_3 is the expense involved in fertilizer storage and processing at the farm storage facilities, E_4 is the expense involved in fertilizer application, E_5 is the expense involved in harvesting, handling, and processing of the yield increment due to fertilizer, E_6 is the expense involved in selling the product increment, and E_7 stands for overhead charges.

The net return increment due to fertilizer may be written as:

$$NR_f - NR_0 = (BP_f - BP_0) - E$$

where NR_f is the net return from the fertilized area (rubles), NR_0 is the net return from the untreated area, BP_f is the cost of the bulk product (main and by-products from the fertilized area, rubles), and BP_0 is the cost of the bulk product from the untreated area (rubles).

The fertilizer profit P (%) is defined using the formula:

$$P = \frac{(MP + BP) - E}{E} \cdot 100 \left(\text{or } P = \frac{NR}{E} \cdot 100 \right)$$

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and the return from additional expenses involved in fertilizer application is determined from the formula

$$R = \frac{MP - BP}{E}$$

Variations in the product cost as a result of fertilizer application may be expressed as:

$$C = \frac{TE}{Y_0} \quad \text{and} \quad C_1 = \frac{TE + AE}{Y_0 + Y_f}$$

where C and C_1 stand for the cost of product unit without and with fertilizers (rubles), respectively, TE stands for the total expenses (without fertilizer) per hectare (rubles), AE stands for the additional expenses involved in fertilizer application per hectare (rubles), Y_0 is the yielding capacity per hectare without any fertilizers being applied or at a comparatively lower fertilizer application rate (centners), and Y_f is the yield increase due to fertilizer per hectare (centners).

The above approach to determine the economic effectiveness of fertilizers has been developed by the chemicalization economics departments of the USSR Research Institute of Agricultural Economics, the USSR Research Institute of Fertilizers and Agronomical Soil Science, the USSR Research Institute of Livestock Breeding, and the USSR Research Institute of Plant Protection.

When this approach is used, the expenses involved in fertilizers should be differentiated from year to year depending on their aftereffect:

Fertilizer type	Year of effect	Expenses (%)
Organic	1st	60
	2nd	30
	3rd	10
Nitrogen	1st	100
Phosphorus	1st	55
	2nd	30
	3rd	15
Potassium	1st	70
	2nd	30

The effect and aftereffect of lime should preferably be taken into account over a period of five to seven years (depending on its application rate) with yearly expenses

involved in liming varying from 20 to 14.3 per cent.

It is better to determine the economic effectiveness of fertilizer application in crop rotation per rotation cycle. The productivity of crop rotation is expressed in fodder or grain units. The cost of marketable produce is given in purchase prices, while that of fodder crops (and by-products) for which no such prices exist is expressed in terms of the cost of a centner of fodder units (purchase price for a centner of oat grain). The indicators of economic effectiveness of the fertilizer system per crop rotation cycle are determined just as for individual crops, using the above formulas in which the value of each parameter per rotation cycle is a sum total covering all rotating crops. For example, the profitability of a fertilizer system is given by the formula:

$$P\,(\%) = \frac{(C_1 + c_1) - E_1 + (C_2 + c_2) - E_2 + \ldots + (C_n + c_n) - E_n}{E_1 + E_2 + \ldots + E_n}\,100$$

where C_1, C_2, ... C_n stand for the cost of the main crop rotation product increment due to fertilizer (rubles); c_1, c_2, ... c_n stand for the cost of the crop rotation by-product increment due to fertilizer (rubles); E_1, E_2, ... E_n stand for the sum of all expenses involved in application of fertilizers to respective rotating crops (rubles).

In comparing fertilizer system options according to economic indicators, preference is given to the option involving the highest yield and net return per hectare, the highest productivity of labour, a low product cost, and high profitability. However, the return from fertilizers may be higher in a fertilizer system where their application rates are lower. In regions with intensive chemicalization of agriculture, the determining indicators of economic effectiveness of fertilizers among fertilizer systems being compared are net return per hectare and yielding capacity. Here, attention should be given to maintaining an optimal nutrient balance in the soil within a crop rotation cycle. In areas of insufficient fertilizer application, the leading economic indicator of fertilizers is the return as a result of yield increase, which permits a more rational use of fertilizers over a larger area. The economic effectiveness of fertilizer application is enhanced by industrialized cropping practices.

Chapter 7

Effect of Fertilizers
on Crop Composition
and Quality

The chief purpose of cultivating farm crops is to obtain such chemicals as proteins, fats, starch, sugars, cellulose, vitamins, alkaloids, essential oils, rubber, and other compounds used as man's and farm animals' food as well as raw materials for the industry. While cultivating crops, farmers strive to maximize yields of high quality crops with a maximum content of the valuable chemical substances for which the crops are grown.

Depending on cropping conditions, the crop quality may vary widely. The protein content in wheat, for example, may vary from 9 to 25 per cent, that of starch in potatoes from 10 to 24 per cent, the content of sugar in sugar beet may vary from 12 to 22 per cent, that of fat in the seeds of oil-yielding plants, sugars and vitamins in fruits and vegetables, alkaloids and essential oils in respective crops may go up or down, depending on the conditions under which they are grown, anywhere within 150 to 200 per cent. This means that, even when yields from the same area are equal, the amount of commercially valuable products may be greater if the crop quality is higher.

In recent years, the yielding capacity and gross outputs of most farm crops in the USSR have increased. However, in some areas, the quality of grain and certain other crops does not meet the requirements imposed by the processing industry and the consumer. Moreover, as a result of low crop quality, product losses in storage, especially those of potatoes, sugar beet, and vegetables, increase considerably. This is why improving the chemical composition of crops and increasing their quality are among the tasks of paramount importance in agricultural production.

The basic processes responsible for a particular quality of crops are, on the one hand, biosynthesis of proteins and other nitrogenous compounds and, on the other, biosynthesis

of carbohydrates or (in seeds of oil plants) fats. These processes occur under different conditions, and, almost invariably, when the biosynthesis of proteins intensifies, accumulation of carbohydrates or fats slows down and, vice versa, as the intensity of protein synthesis decreases, accumulation of carbohydrates in plants proceeds at a faster rate. The effect of many environmental factors on the quantitative and qualitative variability of the chemical composition of plants has been elucidated in recent years. These factors include temperature, moisture content in the soil, air humidity, the quantity and quality of illumination, soil conditions, farming practices, growth stimulants, and so on, yet numerous agrochemical and biochemical studies indicate that one of the most effective and fast-acting factors of variations in the chemical composition of plants and higher crop quality is fertilizers. The effect of fertilizers on the chemical composition of plants resides in that the nutrients taken up by plants from fertilizers are constituents of major organic compounds and increase the content of the latter in crops. Individual nutrients also play a decisive role in plant metabolism.

Application of fertilizers without taking into account the biological characteristics of plants, soil and climatic conditions, and the effect of the fertilizers themselves sometimes lower the crop quality instead of improving it.

By improving the supply of plants with particular nutrients at different stages of growth one can change the direction of metabolic processes as required and promote accumulation of proteins, starch, sugars, fats, alkaloids, and other commercially valuable substances in plants. A lot of studies into the effect of fertilizers on the chemical composition of crops and their quality have been accomplished of late in all soil and climatic zones of the Soviet Union. The general pattern established as a result of these studies can be reduced to the following basic regularities.

The nitrogen taken up by plants is soon converted into amino acids which are indispensable for biosynthesis of proteinaceous substances, nucleic acids, alkaloids, and other compounds. Nitrogen is also a constituent of chlorophyll, some vitamins, hormones, and so on. Therefore, improved

nitrogen nutrition is conducive to more intensive accumulation of these compounds in plants.

Nitrogen deficiency leads to much lower contents of proteins and especially non-protein nitrogenous compounds. The relative content of starch and sugars in the case of inadequate nitrogen nutrition is usually higher than under optimal conditions of such nutrition. However, an acute nitrogen deficiency may lower the content of mobile carbohydrate forms at the expense of cellulose.

The decreasing carbohydrate content as a consequence of heavy application of nitrogen fertilizers can be attributed to the fact that the plant expends, at many steps of nitrogen metabolism (reduction of nitrates to ammonia, biosynthesis of amino acids from ammonia, biosynthesis of amides, nitrogen bases, nucleic acids, proteins, and other nitrogenous compounds), a large amount of the energy it receives primarily in the course of protosynthetic phosphorylation and oxidative degradation of carbohydrates. The carbon skeleton of the emerging nitrogenous compounds is also built from carbohydrates or products of their transformations with the result that during vigorous nitrogen uptake most of the carbon fixed in photosynthesis is spent in the biosynthesis of various nitrogenous compounds rather than carbohydrates Thus, intensive nitrogen nutrition brings down the content of carbohydrates or fats in plants.

Of particular importance to the quality of some farm crops are the forms of the nitrogen fertilizers used. It has been demonstrated that different sources of nitrogen nutrition produce dissimilar effects on the transformation of substances in plants. In particular, during ammonia nitrogen nutrition of plants their metabolism shifts towards accumulation of a greater amount of reduced compounds (essential oils and alkaloids), whereas nitrate nitrogen nutrition promotes formation of oxidized compounds, mainly organic acids.

A significant and in some instances determining effect on most biochemical processes is produced by phosphorus which is directly involved in the synthesis and breakdown of sucrose, starch, proteins, fats, and many other compounds. Under the effect of phosphorus fertilizers, the rate of sucrose, starch, and fat synthesis goes up sharply.

The rate of protein synthesis also increases under the effect of phosphorus, but to a lesser degree than that of sucrose or starch synthesis. Therefore, as a rule, phosphorus deficiency leads to a relatively lower content of sucrose and starch in plants, as compared to the protein content, while phosphorus nutrition speeds up the carbohydrate synthesis rate and to a greater degree than the protein synthesis rate at that.

Potassium produces a positive effect on the photosynthetic rate as well as on the biosynthesis and accumulation of sucrose, starch, and fats in plants. The biosynthesis of proteins is also accelerated by potassium fertilizers applied at optimal rates. Comparison of different sources of nitrogen (ammonia or nitrate) clearly attests to the positive effect of potassium on protein synthesis during ammonia nutrition. Inadequate potassium nutrition slows down the synthesis of sucrose, starch, and fats, while increasing the content of monosaccharides in plants.

Thus, depending on conditions of inorganic nutrition, the chemical composition and quality of crops may undergo pronounced changes.

A high protein content in farm crops is particularly important. Protein cannot be replaced in man's and animals' food by any other substances, the daily protein intake by man ranging from 70 to 100 g. Protein deficiency in food may bring about serious metabolic disturbances.

Increasing protein yields to meet the alimentary requirements of the population is generally recognized as one of the most acute and difficult problems of our times and ranks first in its practical implications. According to the FAO statistics, almost half the Earth's population suffer from protein hunger. This is why scientists and agronomists of all countries have been in search for ways to enhance the protein content in the major farm crops.

In the Soviet Union, the problem of food protein is non-existent because the protein requirements of the population are met almost to the full. Yet the problems stemming from protein deficiency in cattle and poultry feed remain to be solved.

The most readily available, common and inexpensive sources of protein are grain cereals and pulses, hence, emphasis should be placed on increasing the protein content

in these crops. If it is assumed that the average annual grain production in the Soviet Union exceeds 200 million tons at present, one can easily calculate that increasing the protein content in grain crops by a mere per cent provides additional two million and more tons of protein.

The first studies into the effect of fertilizers on the grain of cereal crops were undertaken in the USSR at Pryanish-nikov's laboratory. These studies have shown that protein accumulation is best promoted by nitrogen fertilizers, especially in the Non-Black Earth zone where the harvested grain is usually of poorer quality than in southern regions because of the inherently low soil fertility.

There is a wealth of experimental evidence to the effect that fertilizer application is a prerequisite for higher grain quality in these regions. For example, in experiments carried out on soddy podsolic soils in the Perm Region, the protein content in the kernels of untreated wheat was 11.7 per cent and that of gluten 26.6 per cent. After application of $P_{60}K_{60}$ the protein and gluten contents were 11.9 and 25.9 per cent, respectively, and after $N_{60}P_{60}K_{60}$ was applied, the protein content rose to 14.1 per cent and that of gluten, to 34.2 per cent. Similar results were reported after treatment of other grain crops grown in the Non-Black Earth zone, namely, rye, oat, and barley.

In field experiments with barley, performed at the Belorussian Research Institute of Agriculture on soddy podsolic soils with low mobile phosphorus and exchangeable potassium contents, phosphorus-potassium fertilizers increased grain yields significantly, however, the protein content remained the same and even tended to go down. Nitrogen fertilizers applied against the PK background increased yields further and, when applied at higher rates, nitrogen was expended primarily to raise the protein content in the grain. The overall yield of protein was almost doubled due to fertilizer (Table 7.1).

To increase the quality of grain crops it is extremely important to timely treat them with nitrogen fertilizers. As is known, winter cereals utilize nitrogen best when it is used for dressing in spring. Spring dressing of winter cereals not only increases yields dramatically, but also improves the grain quality. When winter wheat is dressed

Table 7.1. Effect of Fertilizers on Barley Yield and Quality
(averaged over a period of three years)

Experimental conditions	Yield (cent/ha)	Protein (%)	Protein yield (kg/ha)
No fertilizer	14.5	11.0	160
$P_{40}K_{40}$	19.2	10.6	204
$N_{20}P_{40}K_{40}$	22.2	11.3	251
$N_{40}P_{40}K_{40}$	23.9	12.1	289
$N_{60}P_{40}K_{40}$	23.0	13.2	304

in spring with 30 to 60 kg N per hectare, the protein content in the kernels often increases by one or two per cent.

Wheat is the staple cereal of the USSR, and improvement of its processing and baking properties is in the focus of general attention. The basic task at present is to grow strong varieties containing at least 14 per cent protein, according to the standard, and at least 28 per cent of group I gluten.

Protein is accumulated as a result of reutilization of the nitrogenous substances present in vegetative organs before kernels start to form and nitrogen starts being taken up from the soil. Winter wheat often suffers from nitrogen deficiency at the end of the vegetation period. Experiments have shown that by the onset of milky ripeness the grain contains up to 40-50 per cent of the nitrogen usually present in ripe kernels, its content increasing to 70-80 per cent by the time the first signs of gold ripeness appear, while the remaining nitrogen (20-30%) is translocated into the kernels at the gold ripeness stage. If the import of nitrogen slows down or stops altogether at the very end of the vegetation period, the grain will end up with a lower protein content. Therefore, to increase the protein content in the grain, it is most important to ensure adequate nitrogen nutrition of the plants at later stages, namely those of earing, flowering, and early grain formation. The nitrogen taken up at these stages is vigorously translocated into the kernels, and protein synthesis is more intensive in them at the grain formation stage.

This has been borne out by a great number of experiments carried out in different soil and climatic zones of the USSR. For example, in Mosolov's experiments, the yield remained virtually the same when the plants were dressed late, but the grain quality improved considerably. The most significant increase in the contents of protein (by 2.8%) and gluten (by 10%) was observed when nitrogen fertilizers were applied at the early grain formation stage (Table 7.2). It should be remembered, though, that late

Table 7.2. Effect of Nitrogen Dressing on the Yield and Quality of the Bezostaya I Wheat Grain (Stavropol Territory)

Experimental conditions	Yield (cent/ha)	Protein (%)	Raw gluten (%)
Background (control)	39.6	16.4	23.6
Background + N_{45} at the shooting stage	42.5	17.3	24.0
Background + N_{45} at the earing stage	41.2	18.2	30.0
Background + N_{45} at the early grain formation stage	39.0	19.2	33.8

dressings with nitrogen produce such a positive effect only if the plants are adequately supplied with moisture.

As was recently established, plants are capable of taking up intensively and assimilating via leaves ammonia and nitrate salts as well as urea when solutions of these substances are used for foliar dressing, the processes of their assimilation and transformation after foliar uptake being basically the same as those following uptake via roots. Consequently, foliar dressing of plants with nitrogen fertilizers has found extensive application. Foliar dressing practices involve, primarily, urea or ammonium nitrate solutions. Experiments have shown that urea produces even better results than ammonium nitrate, the reason being that urea is not only a source of nitrogen but also a physiologically active substance. Urea promotes the photosynthesizing activity of leaves and the activity of proteolytic enzymes in the latter; the proteins present in leaves break down at a faster rate with the result that the export of nitro-

genous compounds from leaves into the ripening kernels is intensified.

Experiments with ^{15}N-labelled urea indicate that the nitrogen of urea supplied at later stages of plant development is incorporated mainly into prolamines and glutelins, that is, gluten proteins. Under favourable weather conditions, the gluten content in the grain increases as a result of such dressing by 7 to 10 per cent, which allows farms to increase yields of strong wheat varieties.

Foliar dressing of wheat with urea substantially improves the baking properties of flour. Experiments carried out at Moscow State University on soddy podsolic soils in the Moscow Region have demonstrated that, apart from considerably increasing the protein and gluten content in kernels, late foliar dressing of wheat with urea at an average rate of 30 kg N/ha over a two-year period raised the flour "vigour" from 349×10^{-4} J on the control plot to 509×10^{-4} J, the dough resilience increasing from 179 mm (control) to 189 mm*.

Foliar dressing of wheat with urea solutions is done by aerial spraying at the flowering/early milky ripeness stage, the nitrogen rates ranging from 30 to 50 kg/ha, and the solution concentration at mist spraying may be as high as 30 per cent without any danger of leaf burns.

What is then the effect of the other basic nutrients, that is, phosphorus and potassium, on the quality of wheat? Most investigators believe that enhancement of phosphorus nutrition alone reduces the protein content in the grain and adversely affects the baking properties of flour. For example, as can be inferred from Sozinov's data averaged over 44 experiments, application of superphosphate at a rate of 20 to 30 kg P_2O_5 per hectare to winter wheat lowers the gluten content from 33 to 30.9 per cent, grain flintiness from 64 to 49 per cent, and flour "vigour" from 261×10^{-4} to 219×10^{-4} J.

In Mosolov's greenhouse experiments with spring wheat treated with (g/pot) $N_{0.75} P_{0.5} K_{0.5}$, the grain yield was

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* Flour "vigour" means work, in joules, expended to blow a film of dough into a bubble till it breaks and is determined using an alveograph. Dough resilience is characterized by the maximum resistance of the dough film (in mm) blown into a bubble.

15.3 g per pot, the protein content was 12.9 per cent, and the protein yield was 1.97 g/pot. Heavier application of phosphorus at the same nitrogen and potassium rates increased the grain yield up to 17.2 g/pot, yet the protein content went down by 2.5 per cent to only 10.4 per cent. The protein yield also decreased to 1.79 g/pot.

The negative effect of increased phosphorus rates on the quality of wheat does not mean, of course, that phosphorus is not needed by plants or that it adversely affects the biosynthesis of proteins. The protein content in kernels is reduced largely for two reasons. Phosphorus speeds up the growth of plants, increases the yield of grain and vegetable matter, which leads to "dilution" of nitrogen in the plant, the latter suffers from nitrogen deficiency, and kernels are formed with a lower protein content. This is why one should maintain the proper nitrogen to phosphorus ratio throughout the growth period. The second reason why phosphorus lowers the quality of grain is that, unlike urea, phosphorus stimulates biosynthesis of proteins in leaves, rather than their degradation, with the result that the export of nitrogen from leaves and its reutilization during the kernel ripening period are suppressed and the kernels receive less nitrogenous substances.

As was observed in some experiments on soils with an extremely low mobile phosphorus content, phosphorus fertilizers not only did not decrease but even increased the protein content in wheat grain to some extent.

Potassium fertilizers applied at usual rates leave unchanged or even raise somewhat the protein content in wheat kernels.

However, increased rates of potassium fertilizers may significantly reduce the protein content in kernels. For example, in experiments carried out by Mosolov and Vorob'ev, who grew wheat on soddy podsolic soil, the percentage content of protein in kernels varied as follows, depending on the fertilizers used:

No fertilizer	NP	NPK	NPK$_2$*
13.1	17.2	18.4	12.5

* K_2 stands for potassium applied at a double rate.

The negative effect of high potassium fertilizer rates on the protein content in the grain can be explained as follows. Grain crops are characterized by an inverse relationship between protein and starch contents: the more starch is accumulated in kernels, the less proteins they contain. Potassium is doubtless necessary in sizable amounts for normal plant growth and protein biosynthesis, however, it stimulates synthesis and transport of carbohydrates to a greater degree than those of nitrogenous substances. Therefore, application of potassium fertilizers at higher rates substantially intensifies the synthesis of carbohydrates and their translocation into ripening kernels where a lot of starch is accumulated and the relative protein content goes down accordingly.

The effect of fertilizers on the quality of other grain crops is basically similar to that on wheat quality.

Of particular interest is the variability of maize grain quality under the effect of fertilizers. This crop can produce very high yields, yet the protein content in its grain is insufficient, which lowers the value of maize as fodder and foodstuff. Hence, the great deal of attention given to studies into the effect of cultivation conditions on the chemical composition of maize grain.

A maximum increase in maize grain yields and protein content can be achieved only by using nitrogen fertilizers. According to Khanter, application of nitrogen fertilizers to maize changes the yield of grain and the protein content in it in the following manner (Table 7.3).

Table 7.3. Effect of Nitrogen on Maize Yields and Quality

Nitrogen rate (kg/ha)	Grain yield (cent/ha)	Protein content in grain (%)	Protein yield (kg/ha)
0	40.7	6.92	282
45	57.0	7.27	415
90	74.5	7.86	586
112	83.4	8.06	672
134	88.6	8.45	748
179	92.5	8.74	806
224	92.7	9.30	862

Thus, nitrogen fertilizers increased the overall nitrogen yield per unit area two to three times.

Similar results were reported by other experimenters.

The vegetable matter of maize, just as its grain, is characterized by a low protein content, which can be effectively raised in maize by foliar dressing with urea solutions. Once urea reaches leaves, it easily penetrates the tissues and is rapidly converted into amino acids and proteins, whereby the fodder is enriched with protein by a factor exceeding 1.5. According to summarized foliar dressing data presented by research institutes, urea should be aerially sprayed at the milky and milky-wax ripeness stages (2 to 3 weeks before harvesting for silage), the solution concentration being 20 to 25 per cent and the spraying rate, 400 to 500 litres of the solution per hectare. As a result of such spraying, the protein content in maize increases by 55 to 60 per cent (250-350 kg protein per hectare), and the content of digestible protein increases from 60-65 to 90-105 g per fodder unit. Calculations indicate that one kilogram of urea used in foliar dressing may yield additional 1.6 to 2 kg of protein which is sufficient to get 15 to 25 kg of milk from cows.

In the context of the vegetable protein problem, legumes acquire special importance since they contain two to three times as much protein as grain crops. Extension of pulse cultivation areas permits the protein balance in fodder to be drastically improved and the diversity of foodstuffs for people to be enhanced. Since legumes take up atmospheric nitrogen with the aid of nodule bacteria, their quality and protein content are determined primarily by the rate of nitrogen fixation by these bacteria, the rest of the factors being but secondary as far as the chemical composition of these crops is concerned. Consequently, in order to obtain high yields of top quality legumes, conditions must be created conducive to intensive atmospheric nitrogen fixation. Such conditions may be provided, first of all, by inoculation of legumes with appropriate strains of nodule bacteria and liming of acid soils. The major factors for improved pulse quality include phosphorus and potassium fertilizers because they stimulate formation and growth of nodules and intensify nitrogen fixation. In experiments

conducted by research workers of the USSR Institute of Plant Growing, pea of the Maslichny variety grown in the Leningrad Region without treatment contained 25.2 per cent protein in its seeds. Application of 45 kg P_2O_5 and the same amount of K_2O per hectare increased the protein content to 27.4 per cent, and application of 90 kg P_2O_5 and 135 kg K_2O per hectare increased the protein content to 31.5 per cent.

In experiments of the Voronezh Institute of Agriculture on leached chernozem, the yields of pea increased, on the average over a period of five years, from 25.6 cent/ha on the control plot to 31.6 cent/ha after application of P_{60}, the protein content increasing from 22.7 to 24.2 per cent. Application of $P_{60}K_{60}$ increased the yield of pea to 32.7 cent/ha and the protein content, to 25.4 per cent. Thus, phosphorus-potassium fertilizers increased the protein yield from 580 to 830 kg/ha.

As has been established in recent years, the quality of legumes is also improved by some micronutrients, particularly when molybdenum fertilizers are used. Molybdenum raises yields and the protein content in seeds more than any other micronutrient because it stimulates atmospheric nitrogen fixation by leguminous plants.

In experiments performed at the Uman Agricultural Institute on podsolized chernozem, the average (4 years) pea yield without treatment was 21.5 cent/ha with a protein content of 21.4 per cent. Application of molybdenum fertilizers to pea increased the yield to 24.3 cent/ha and the protein content, to 22.3 per cent.

Of topical interest, apart from the overall content of proteins in farm crops, is also the quality of the proteins themselves and, in the first place, their fractional and amino acid compositions. Determination of the amino acid composition of proteins is becoming indispensable in crop quality analysis. Proteins consist of 20 different amino acids. Yet not all of them have the same nutritive value. Many amino acids may be synthesized in the human or animal organism from nitrogen-free compounds and ammonia or other amino acids, then become involved in formation of protein molecules necessary to build organs and tissues of the animal body. However, certain amino acids

cannot be synthesized in this fashion and must be received with food. These are what is termed as essential amino acids.

There are eight amino acids that are essential for man, and an adult must receive the following average quantities of these amino acids every day: 1.0 g of tryptophan, 5.5 g of lysin, 7 g of leucine, 4 g of isoleucine, 5 g of valine, 3.5 g of methionine, 5 g of phenylalanine, and 4 g of threonine. When the food contains little or none of one of the several amino acids, serious metabolic disturbances occur, which may lead to grave diseases.

Proteins differ widely in amino acid composition, including the content of essential amino acids. Some proteins contain all amino acids in quantities sufficient for man and animal alike. Such proteins are referred to as complete proteins. These include the proteins of eggs, milk, and meat. However, many proteins, primarily of vegetable origin, do not contain at all or contain small amounts of one or several essential amino acids. For example, proteins of grain cereals contain insufficient amounts of lysin and tryptophan, leguminous proteins are deficient in methionine, proteins of potato tubers contain very little valine, and so on. These are known as incomplete proteins.

Man seldom satisfies his protein and essential amino acid requirements merely by eating a particular type of food. Yet this is often the case with farm animals, especially pigs and poultry. Therefore, one must take into account not only the total protein content in animal feed, but also the content of essential amino acids in the proteins.

The biological nutritive value of proteins is determined by comparing all properties of a given protein, primarily its complete amino acid composition, with those of the most valuable and easily digestible egg or milk proteins. If the biological nutritive value of egg proteins is taken as 100 per cent, the proteins of some farm crops will have the following nutritive values (%): wheat, 62-67; maize, 52-58, barley, 64; pulses, 75-85, potatoes, 85. It should be borne in mind that we are not speaking of the overall value of a foodstuff with respect to eggs or milk, but the value of the proteins present in the foodstuff.

As has been shown above, the protein content in farm

crops may vary widely depending on the fertilizers used, the total protein yield per unit area increasing two to three times if the fertilizers are properly applied.

Then, the question arises whether the amino acid composition of proteins and the content of essential amino acids in them are influenced by fertilizers. Experiments suggest that the composition of grain crop proteins may change under the effect of nitrogen fertilizers, particularly when they are applied late. In this case, synthesized in the grain are large amounts of alcohol- and alkali-soluble proteins, and their percentage in the protein complex increases. It has been shown that individual protein fractions differ in amino acid composition, alcohol- (prolamines) and alkali-soluble (glutelins) proteins containing less essential amino acids and more glutamic acid, proline, and amides, as compared to water- (albumins) and salt-soluble (globulins) proteins. Therefore, nitrogen fertilizers may lower slightly the content of essential amino acids in total proteins and their nutritive value. If the quantity of essential amino acids is calculated in terms of dry grain weight, an increase in the percentage protein content in the grain brings about a slight increase in the content of essential amino acids there.

It should be emphasized, however, that the composition of individual vegetable proteins undergoes no changes under the effect of fertilizers, that it remains stable and is determined by genetic factors and the plant species. Fertilizers may change only the fractional composition of proteins but not their amino acid composition.

Significant changes induced by fertilizers are observed in the accumulation of not only nitrogenous but also other substances in plants, starch in particular. Changes in the starch content are by far most important in potatoes where it is the basic indicator of tuber quality, especially when tubers are intended for factory processing.

Inorganic fertilizers containing large amounts of chlorine reduce the starch content, the reduction being sometimes so pronounced that starch yields from fertilized and untreated plots are equal. In such cases, the expenses involved in fertilizer application are not justified at all. Pryanishnikov reported the results of perennial experiments, indicating that

application of potassium sulphate to potatoes brought the average starch content in tubers to 20 per cent, whereas application of a 40% potassic salt reduced it to 17 per cent and that of carnallite, even to 16 per cent. Therefore, in applying potassium fertilizers to potatoes it is very important to select correctly both their suitable forms and application techniques and schedules such that would not lower the starch content in potato tubers.

High-chlorine fertilizers lower the quality of buckwheat, tobacco, and some other crops. Using potassium sulphates instead of chlorides or applying chlorine-containing potassium fertilizers well in advance, when chlorine is leached in autumn or in spring, substantially increases the yield and quality of these crops.

The potato belongs to crops with high potassium requirements. Potassium stimulates synthesis of carbohydrates, especially starch, both in leaves and in tubers. When potassium is deficient, the carbohydrates imported into tubers are converted into starch extremely slowly.

One of the reasons why the starch content is reduced by heavy application of chlorine-containing fertilizers is activation of amylases by chloride ions. Amylases catalyze starch hydrolysis with the result that the starch content in tubers remains low. To improve the quality of potatoes, it is important to treat them with chlorine-free potassium fertilizers (Table 7.4).

Table 7.4. Effect of Various Forms of Potassium Fertilizers on the Yield and Quality of Potatoes (averaged over 6 years)

Experimental conditions	Yield (cent/ha)	Starch content (%)	Starch yield (cent/ha)
$N_{90}P_{60}$ (background)	164	16.5	27.1
Background + potassium chloride	206	15.3	31.4
Background + potassium sulphate	202	16.1	32.6
Background + potassium nitrate	204	16.0	32.5
Background + schoenite	211	16.0	33.7
Background + 40% potassic salt	207	15.0	30.9

In these experiments, carried out at the agrochemical experimental station in Ramenskoye on soddy podsolic loamy soils with a low mobile phosphorus content and a medium content of exchangeable potassium, all forms of potassium fertilizers were applied at rates of 60 kg K_2O per hectare. The tuber yield was raised equally by all forms, but chlorine-containing ones lowered the starch content in tubers. Heavier application of such fertilizers lowers the starch content even further. For example, application of potassium chloride at increasing rates to potatoes grown on soddy podsolic sandy loam at the Brest Regional Experimental Station changed the starch content in tubers as follows (%): no treatment, 16.1; $N_{60}P_{60}$, 15.1; $N_{60}P_{60}K_{60}$, 15.0; $N_{60}P_{60}K_{90}$, 14.1; $N_{60}P_{60}K_{120}$, 13.5. Consequently, application of potassium fertilizers at high rates directly to potatoes sharply lowers the starch content in tubers, they become watery, and their quality is impaired. To mitigate the negative effect of chlorine-containing potassium fertilizers they must be applied in autumn.

Nitrogen fertilizers contribute markedly to higher tuber yields, but they are also responsible for a slight decrease in starch content. The results averaged over 21 experiments carried out in the German Democratic Republic indicate that the starch content in the tubers of potato plants treated with nitrogen is as follows: 16.4 per cent without treatment, 16.2 per cent after treatment with N_{40}, 16.1 per cent after treatment with N_{80}, and 15.9 per cent after treatment with N_{100}. When nitrogen is taken up at a faster rate, the products of carbohydrate degradation are expended in binding ammonia and formation of amino acids and proteins with the result that the carbohydrate content in the plants goes down.

Phosphorus fertilizers increase the starch content in potato tubers. There is a wealth of experimental evidence that the starch content in tubers is usually increased by treatment with phosphorus by one to two per cent.

The potato is a major source of ascorbic acid (vitamin C). The content of this vitamin in tubers usually ranges from 15 to 25 mg per cent. Heavy application of nitrogen fertilizers to this crop lowers the content of vitamin C considerably. On the other hand, application of phosphorus and potassium

fertilizers eliminates the harmful effect of nitrogen fertilizers applied alone on the biosynthesis of ascorbic acid.

Peeled raw potato tubers turn dark in air. Darkening of the tuber pulp is a serious factor of potato quality deterioration. It stems from the fact that atmospheric oxygen assisted by enzymes oxidizes the amino acid tyrosine into melanins characterized by dark colour. In addition, most phenolic compounds also yield dark-coloured products during oxidation involving iron. When tubers contain larger amounts of potassium (at least 2-2.5% dw), the darkening of tubers is much less pronounced. Therefore, to prevent potato tubers from darkening, it is recommended to apply potassium fertilizers at higher rates. Heavy application of nitrogen fertilizers alone intensifies the darkening of potato tuber pulp.

Other important chemical compounds for which most crops are cultivated include sucrose and monosaccharides. The processing and fodder value of sugar beet and many vegetables is determined primarily by the sugar content in them. Therefore, the cultivation of sugar beet and vegetable crops calls for conditions ensuring accumulation of as much sugars as possible. It should be remembered that at current production levels increasing the sugar content in beets by a mere 0.1 per cent allows additional 80 thousand tons of sugar to be produced.

In the first half of the vegetation period, sugar beet requires such conditions when the formation of tops proceeds at the fastest rate possible. This is achieved by applying nitrogen, phosphorus, and potassium fertilizers. During the second half of the vegetation period, the conditions for increasing the sugar content in roots are more favourable when the nitrogen nutrition level is lowered somewhat, while phosphorus and potassium nutrition is intensified. Increased nitrogen nutrition during this period stimulates the growth of tops and accumulation of nitrogenous compounds in the plants so that the sugar content in roots may go down significantly. Cook reported results averaged over 41 field experiments aimed at elucidating the effect of high nitrogen rates on the sugar content in sugar beet. In these experiments, application of 75, 150, and 224 kg N/ha brought the sugar content in roots to 16.6, 16.2, and 15.8

per cent, respectively, the corresponding total sugar yields being, accordingly, 66.3, 67, and 64.9 centners per hectare. Thus, excessive application of nitrogen fertilizers decreases the sugar yield per unit area instead of doing the opposite.

In 264 experiments conducted by the State Agrochemical Service in the major sugar beet producing regions of the Soviet Union, application of fertilizers at the rate $N_{70}P_{60-80}K_{65-75}$ increased the sugar content in beet roots by 0.2 to 0.3 per cent, as compared to the control plots, the sugar yield per hectare increasing by 8 to 18 per cent. When the nitrogen rates were raised from 70 to 120 kg/ha against the same background of phosphorus-potassium fertilizers, the sugar content in roots was lowered by 0.3 to 0.5 per cent.

Phosphorus fertilizers often produce a positive effect on the yields and quality of root crops. In experiments carried out by Yeleshev and Basibekov on light chestnut soils in southern Kazakhstan with a medium content of mobile phosphorus and a high available potassium content, phosphorus fertilizers changed both the yield and quality of sugar beet perceptibly (Table 7.5).

Table 7.5. Effect of Phosphorus Fertilizers on the Yield and Quality of Sugar Beet Roots (averaged over 3 years)

Experimental conditions	Yield (cent/ha)	Sugar (%)	Sugar yield (cent/ha)	Nitrogen (% dw)		
				total	pro-tein	harm-ful
No treatment	207	14.9	29.8	0.83	0.50	0.33
$N_{90}K_{100}$ (background)	248	14.2	35.2	1.24	0.72	0.49
Background + P_{120}	473	15.5	73.2	1.02	0.64	0.37
Background + P_{180}	501	15.7	77.9	1.05	0.69	0.36

Phosphorus fertilizers increased the sugar content in roots from 14.9 (background) to 15.7 per cent, the sugar yield being doubled and reaching 70 cent/ha and even more. Besides, phosphorus fertilizers reduce considerably the content of harmful nitrogen in roots, which lowers the sugar yield when sugar beets are processed.

The sugar content in most vegetable crops is changed by fertilizer application in the same manner as in sugar

beet. Furthermore, fertilizers increase the content of some vitamins in roots.

Of extremely high importance is improving the quality of sunflower which is the main oil-yielding crop in the Soviet Union. Suffice it to say that increasing the fat content in sunflower seeds only by one per cent at the present production level gives additional 60 thousand tons of vegetable oil.

Fats in plants derive from carbohydrates, and there is an inverse relationship between the protein and fat contents: the higher the fat content, the less protein in seeds, and vice versa. This is why the fat content in seeds can be increased by creating nutrition conditions conducive to carbohydrate accumulation and, consequently, intensification of fat synthesis in seeds and decrease in the protein content.

The most positive effect on the fat content in seeds is exerted by phosphorus and potassium fertilizers. Their application increases the fat content in seeds by two to four per cent. Nitrogen fertilizers intensify protein synthesis with the result that the content of proteins in seeds goes up at the expense of fats. A decrease in the fat content in seeds is most pronounced under the effect of nitrogen fertilizers applied to oil crops cultivated on chernozems and in low-rainfall regions.

The effect of fertilizers on the fat content in seeds becomes evident from experiments with sunflower, conducted in the Voronezh Region (% fats in the kernel): no treatment, 49.4; treament with urea (30 kg N/ha), 43.8; treatment with precipitate (45 kg P_2O_5 per ha), 52.2; treatment with potassic salt (45 kg K_2O per ha), 51.6. Similar results were obtained in experiments carried out in the Moldavian SSR, Krasnodar Territory, and other regions.

The fat content in seeds is most tangibly affected by nitrogen and phosphorus nutrition at the flowering and ripening stages. It has already been mentioned that the protein content in the kernels of grain crops increases appreciably when plants take up more nitrogen at the ripening stage. A similar picture is observed in oil crops as well. However, since intensified protein synthesis in plants lowers the content of the carbohydrates from which fats are de-

rived, the fat content in seeds under such conditions drops to a greater degree.

It should be pointed out that nitrogen fertilizers, especially for soils with low nitrogen content and in high-rainfall regions, are indispensable in oil crop cultivation. Nitrogen deficiency inhibits plant growth and development of the assimilation surface so that small amounts of carbohydrates are produced in plants during the ripening period, and yields are usually low with a decreased fat content in seeds.

Along with changes in the fat content, induced by fertilizers, the qualitative composition of the fat is also altered. This becomes important when it is remembered that some unsaturated fatty acids (linoleic, linolenic, and arachidonic) cannot be synthesized in the human organism, yet they are involved in metabolism and must be present in the food. These unsaturated fatty acids are classified with vitamins, and their complex is referred to as vitamin F. High contents of these acids on oil enhance its nutritive value. Moreover, they improve the technical properties of the oil in that it dries more quickly and yields drying oil and lacquer of better quality. Sunflower oil contains about 10 per cent saturated fatty acids (palmitic and stearic), about 20 per cent oleic acid, and about 70 per cent of the essential linoleic acid. Nitrogen fertilizers exert the most pronounced effect on the composition of fatty acids in sunflower oil. In greenhouse experiments conducted by Panchenko on leached chernozem against the PK background, the content of fatty acids in the oil squeezed from seeds of sunflower of the Peredovik variety varied as follows (% of total fatty acids):

	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
$N_{0.2}^{*}$	6.6	1.8	21.2	70.3
$N_{0.4}$	7.7	2.2	21.5	68.1
$N_{0.8}$	5.6	3.3	41.8	49.1

Application of nitrogen at rates above normal led to a slight increase in the saturated fatty acid content and a sharp increase in the oleic acid content in the oil with a simultaneous decrease in the content of linoleic acid,

* $N_{0.2}$, $N_{0.4}$, $N_{0.8}$ stand for grams of nitrogen per pot.

that is, the quality of oil is lowered considerably by application of nitrogen fertilizers.

Phosphorus and potassium fertilizers usually cause a slight decrease in the content of saturated fatty acids and a tangible increase in the linoleic acid content, that is, the oil quality is improved. Similar results were obtained in field experiments.

Thus, the factors responsible for a lower fat content in seeds impair the oil quality which is improved by a higher fat content.

We have reviewed in brief the effect of fertilizers on the content of such basic substances as proteins, carbohydrates, and fats which determine the nutritive, fodder, and technical value of farm products.

There is evidence to the effect that fertilizers change the content of many other substances as well, such as vitamins, essential oils, alkaloids, and organic acids. Proper use of fertilizers may significantly increase the content of these valuable substances in crops.

There are no general prescriptions as regards improvement of crop quality. In each particular case, when fertilizers are applied to improve the quality of crops, one must take into consideration the role of individual nutrients in the life of plants, their biological characteristics, the basic pattern of plant metabolism, properties of fertilizers and the soil, and other factors. In other words, the agronomist must be well versed in agrochemical and biochemical theory and skilfully apply it in practice. Then, the yields and quality of farm crops may be increased drastically without spending more money on fertilizers.

Field and Greenhouse Experiments in Agricultural Chemistry

8.1 Field Experiments in Agrochemistry

A field experiment with fertilizers is a trial carried out in the field to determine the effect of fertilizers on the yields and quality of farm crops as well as soil fertility.

Field experiments are widely used in agrochemistry and constitute the basic method for studying the effect of fertilizers, developing and substantiating rational techniques of their application, and preparing fertilizer systems for various uses in agriculture.

Field experimentation provides tools for assessing the effectiveness of various fertilizers in different soil and climatic zones as well as in areas where different farming practices are used, establishing optimal rates and combinations of nutrients to maximize yields of crops and improve their quality, prescribing fertilizer application schedules and techniques, and examining fertilizer application in combination with other cropping procedures.

Field experiments with fertilizers are carried out under natural, typical field conditions on a specially assigned plot, and their results are used for practical purposes and implemented in farm production. Such experiments provide the theoretical guidelines for state enterprises to produce inorganic fertilizers and to supply them to collective and state farms.

Field experiments with fertilizers may be classified as follows.

Farm experiment, a field experiment which permits establishing the effect of fertilizers on crop yields and quality under actual farming conditions.

Stationary experiment, a field experiment with systematic application of fertilizers, conducted on a single plot, in crop rotation, or with the same crop cultivated over a period of several years.

Short-term experiment, a field experiment with fertilizers, in which their effect on crop yields and quality is studied within a period of two to three years under identical soil conditions.

Small-plot experiment, a field experiment conducted on plots not exceeding ten square metres in area.

Microplot experiment, a field experiment conducted on microplots with a natural or filled arable layer.

Extensive experimentation, field experiments with fertilizers, conducted concurrently at several stations using the same experimental procedure.

Geographic network of experiments, a network of field experiments with fertilizers, conducted at experimental stations in different geographic zones of the country, following an approved program.

Factorial experiment, a field experiment in which the levels of each factor under examination are associated with all levels of the rest of the factors.

Properly conducted field experiments providing reliable theoretical and practical corollaries for the agronomical science must satisfy the following basic methodological criteria: (1) the principle of single difference or comparability, (2) typicalness, (3) accuracy of the results, (4) validity, and (5) documentation.

The *principle of single difference*, or, in other words, identity of all experimental variables except for the one of interest, is an attribute of a correctly conducted experiment.

However, satisfying this criterion without reservation and a formal approach to doing this may lead to *a fortiori* incorrect comparisons and conclusions. For example, if this criterion is to be satisfied, the effect of nitrogen and phosphorus fertilizers on winter crops should be studied under identical conditions, that is, at the same application time and technique, but such an approach would be formal because it is agronomically more appropriate to apply each fertilizer at optimal times (phosphorus fertilizers are normally used for basal application and row placement at seeding, while nitrogen ones are recommended for dressing in spring).

In perennial, or long-term, experiments, strict adherence

to invariable farming procedures (crop variety, cultivation techniques, crop rotation, etc.), that is, to the single difference principle, leads to degradation of the process under examination, therefore, changes must be regularly (once per rotation cycle) introduced into the set of conditions that are beyond the scope of investigation.

Thus, the extent to which the single difference principle is satisfied at the experiment preparation, planning, and execution stages depends on the objectives and tasks of the investigation as well as the specific experimental conditions.

Typicalness or representativeness is an essential attribute of the field experiment which must be conducted under soil and climatic conditions typical of the region in question. Other conditions, such as farming and management ones, must be typical, too. If this criterion is not met, the results of field experiments will be useless because of their being at variance with the natural, farming, or management conditions. An important generalized measure of the agrotechnical level is the height of crop stand, and the agricultural background of fertilizer experiments must be amplified.

The *accuracy of experimental results* implies the following. The quantitative data obtained by measuring the yield are but an approximate expression of the true results in view of the fact that establishment and execution of an experiment as well as estimation of the yield invariably involve errors. Of course, the smaller the difference between the true result and the estimates, the more accurate the experiment. The errors in field experimentation, which distort the true results, stem primarily from inaccurate measurements and weighing. The same error arising from measurement or weighing on a plot 10 m² in area will be magnified a hundred times as compared to a plot with an area of 1000 m², hence, the smaller the plot, the more accurately all measurements must be taken there. Another major source of errors in a field experiment is the irregular soil fertility. The irregularity of a plot may be caused by different soils, relief, and microrelief over its area as well as discrepancies in cultivation and other aspects of management. Random errors may also occur in field experiments due to lapses and gaps in sowing, damage and losses

sustained in the course of the experiment and during harvesting.

The accuracy of a field experiment (relative error of the sample mean, $S_{\bar{x}}$ %) is a generalized statistical measure of variability of the experimental results and is established by mathematical processing of the field experiment data with recourse to methods of variation statistics and is characterized by the magnitude of the random error of the mean expressed as a percentage of the yield averaged over the entire experiment (or one of its variants), the formula from which it is determined being as follows:

$$S_{\bar{x}}\% = \frac{S_{\bar{x}} \cdot 100}{\bar{x}}$$

where $S_{\bar{x}}$ is the magnitude of the arithmetic mean error and $\bar{x}$ is the average yield.

The requirements to the field experiment accuracy vary depending on the task pursued by experimentation, the magnitude of the anticipated effect, and the desired reliability of the results.

Validity of the Experiment. For objective assessment of the practical value of the experimental results so that they could be recommended to farms and for defining the essential difference between the process under examination and the control, it is absolutely necessary that the experiment be valid. The accuracy and validity of an experiment are two requirements that are closely associated but not identical. Distinction is made between two definitions of validity: (a) validity in essence and (b) validity and significance of the field experiment results.

The conformity of a field experiment to the tasks pursued, that is, a logically justified and correctly prepared experimental scheme and program, the adequacy of the background and farming procedures, as well as experimentation at a high methodological and technical level ensure the validity in essence.

It is mathematical processing of the experimental results that will tell whether they are valid or significant, that is, such processing will provide mathematical proof of the differences (in terms of yield increase) between the compared variants.

Experimental Documentation. An important methodolog-
ical requirement to be met by field experimentation is keep-
ing the necessary records. Sufficiently complete and accurate
documentation will enable implementation of the exper-
imental results in farming practice and, if necessary, it will
permit replication of the experiment under conditions as
close as possible to the original ones. The primary observa-
tions are recorded on a daily basis with summaries of each
field experiment entered in a log.

8.1.1 Selection of the Area for Field Experimentation

The area for field experimentation must be typical of the
region of interest. The results of an experiment conducted
on a soil which is not typical of a given farm or region
cannot be implemented in farming practice. The soil cover
of the experimental area must be as uniform as possible
because its irregularities enhance the experimental error
and render the experimental results less valid, which is
why the area must be subjected to soil and agrochemical
analyses before the experiment is established.

Prior to establishment of the experiment, it is important
to know the history of the area being selected over the past
three to four years. It must have been seeded with the
same crop and treated in the same manner, the require-
ments to consistent treatment being especially stringent in
cases where its aftereffect is persistent and where such
treatment appreciably affects the soil fertility (liming,
gypsuming, heavy application of organic and inorganic
fertilizers, especially phosphorus ones, deepening of the
arable layer), the experimental area must be free of weeds
(unless the experiment is aimed at exploring ways to control
weeds), and so on.

The experimental area must be level or have an even one-
sided gradient of 0.01 to 0.025 (1-2.5 m per 100 m) with
plots extending along the slope, otherwise different variants
of the experiment will be conducted under dissimilar mois-
ture conditions. Steeper slopes are not admissible for field
experiments with fertilizers, especially if the experiments
are perennial, because the fertilizers will be washed away
by melt water in spring. Yet, in experiments with gravity

irrigation, optimal moisture content in the soil is achieved
at 0.005 to 0.01 gradients, therefore, the experimental area
must be sloped.

Microrelief considerations are also important in selecting
the experimental area: it must have no depressions, hum-
mocks, double or open furrows. The microrelief require-
ments become particularly stringent in irrigation exper-
iments. The uniformity of an experimental area may also
be affected by random factors (holes, ditches, ejected earth,
holes left after stumping, remnants of fertilizer piles and
stacks, etc.). The experimental area must be at a distance
of at least 200 to 400 m from streams, ponds, and gullies,
40 to 50 m from buildings and dense forest, 25 to 30 m from
singly standing trees, and 10 m from clean fences. The
experimental area must not be traversed by roads sep-
arated from it by a 5- to 10-m wide defensive strip.

8.1.2 Preparation of the Experimental Area

To provide for uniform soil fertility and to study care-
fully the homogeneity of the soil, the area selected for exper-
imentation is sown in advance for reconnaissance and equal-
izing purposes with account being taken of yields on in-
dividual plots.

Distinction must be made between soil irregularity,
which depends on natural factors (relief of the experimental
area, soil genesis) and has to be reconciled with, and irreg-
ularity of soil fertility (due to different fertilizers, different
cultivation techniques, different crops, etc.) which can be
eliminated by equalizing sowing within a period of two
to three years. Unlike sowing as a routine farming activity,
the equalizing ones are performed at a high agrotechnical
level. Such sowing not only equalizes soil fertility, but
also creates the necessary agricultural background for the
experiment to be conducted. The last year of equalizing
sowing is used for reconnaissance with account being taken
of yields on individual plots in order to identify the com-
ponents of soil fertility irregularity, most essential for
establishment of the experiment.

The area sown in advance for reconnaissance and equaliz-
ing purposes is tilled within a definite period of time and

in a uniform manner, then sown carefully, without lapses, with a crop sensitive to changes in soil fertility but withstanding adverse climatic conditions well. Therefore, sown most often for reconnaissance purposes are such cereal crops as oat, barley, and spring wheat. Reconnaissance sowing is an arduous affair because yields are recorded on small plots within a short period of time, which is why such sowing is done mainly when perennial stationary field experiments are established.

Thus, soil and agrochemical soil analyses together with equalizing and reconnaissance sowings ensure that the selected experimental area is most regular in terms of soil fertility. They also provide the basis for experimental plot layout, determination of variants and replications of the experiment, and defining the minimal size and the most effective configuration of plots with predetermined approximate accuracy.

8.1.3 Layout of the Experiment

After the experimental area has been selected and prepared, the next steps aimed at minimizing the differences in initial soil fertility include tying the experiment to the area in question, optimal layout of plots, definition of their sizes and configurations, and determination of replications of the experiment. The number of variants of the experiment depends on the experimental tasks and objectives. The greater the number of variants, the larger the experimental area, hence, the more pronounced the irregularity of soil fertility, and the lower the experimental accuracy.

The field experiment scheme must provide for a minimum number of variants to accomplish the desired task. The optimal number of variants ranges from 12 to 16, a further increase in their number rendering the experimentation procedure much more complicated.

Replication of the Experiment. Even the most careful selection and preparation of the experimental area cannot eliminate the effect of irregular soil fertility.   In order to deal more effectively with the irregularity of soil fertility and obtain more accurate average yield data from one variant to another as well as to estimate the degree

of validity of the yield increases achieved in the variants being compared, the similar plots must be evenly distributed over the experimental area so as to ensure replication in space.

Repetition of the experiment over a period of several years (2-3 years for short-term experiments) will ensure replication in time in view of the fact that the effectiveness of the factor under examination, its effect and aftereffect will be determined by weather conditions.

The average yields obtained on similar plots will always be more accurate, that is, closer to the true values, than those obtained from individual plots because the random experimental errors causing departures of the yields on similar plots from the estimate will cancel one another. Replication in an experiment gives an indication of the irregularity of soil fertility and its effect on the yields from similar plots.

Thus, replication of the experiment in space and in time provides not only essential and mathematically valid conclusions, but also information as regards the length of the aftereffect of the factor (fertilizer) under investigation and its dependence on weather conditions.

In fertilizer experiments, similar plots may be arranged in tiers, ranging in number from two to eight and more per tier. Increasing the number of similar plots in a tier perceptibly enhances the experimental accuracy, although the experimental procedure becomes too complicated and the experimental area sharply increases in extent.

In field experiments with fertilizers, four plots in a tier are optimal for stationary experimentation and six to eight plots per tier are optimal for experiments requiring a high degree of accuracy.

Duplication of an experiment is most often done at farms where experiments are established on plots more than 1000 m² in area. However, duplication does not always ensure the required experimental accuracy because of the risk that experimentation on one of the plots may fail, the failed variant cannot be replicated and loses scientific value.

Replication (n) of an experiment, which must be known when the latter is established, can be calculated using the

formula:

$$n = \left(\frac{V}{S_{\bar{x}}}\right)^2$$

where V is the coefficient of variation or variability and $S_{\bar{x}}$ is the relative error of the mean.

The coefficient of variation or variability (V) can most accurately be determined from the results of split accounting of the yield although, as has been stated above, reconnaissance sowing with account being taken of the yields from different plots is not done for every field experiment. Therefore, for approximate calculations one can use Peregudov's data who has established the following coefficients of variation (V): an average of 10 per cent (varying from 5 to 25%) for plots 100 m² in size, 5 to 6 per cent for plots 300 to 500 m² in size, and 5 to 8 per cent for cultivated levelled plots with a carefully planned experimental procedure.

Thus, replication of an experiment depends on the soil cover irregularity, the experimental accuracy as prescribed by the task to be accomplished, and the size of the experimental plot.

The number of plots in an experimental area is determined by the number of variants l and replication (n). The total area assigned for the experiment will depend on the total number of plots $(N \quad ln)$ and the size of the plot which influences the experimental accuracy more than others, the plot size depending on several factors, such as irregularity of soil fertility. The experimental accuracy on areas with insufficiently regular fertility and improperly levelled surface increases not by choosing a larger plot, but by a higher degree of replication as well as through optimization of the plot configuration. The size of the experimental plot also depends on the biological characteristics of the crop under investigation. A plot must accommodate enough plants to compensate for the variability of individual plants in their development. Dospekhov recommends at least 80 to 100 plants per plot in the case of row crops; other workers suggest that a minimum of 40 to 50 potato plants and 60 test maize plants be grown on each plot, therefore, the

plot size for close-growing crops is usually smaller than for row crops.

In determining the plot size, one must also take into consideration the cropping procedures peculiar to the test crop, the crop density, the row spacing, and other factors.

The plot size depends on the duration of the experiment. In perennial field experiments, the plot size is often increased because in the course of experimentation, division of the plots into smaller parcels and introduction of additional variants into the experimental scheme are planned.

Depending on the above factors, the experimental plot size may vary anywhere from 10 to 1000 and more square metres, the optimum, according to most investigators, being 50 to 100 m² for close-growing crops (cereals, pulses, grasses) and 100 to 200 m² for row crops (potatoes, maize, sugar beet). The optimal plot size for flax that ensures high experimental accuracy is 25 to 50 m².

However, there are no standard plot sizes for field experiments and, therefore, in selecting the plot size one must be guided by the smallest area which would ensure the desired experimental accuracy under a given set of conditions, validity of the results, and normal operation of the farm implements used in the experiment.

Distinction should be made between total, or sown, and accounting plot areas (Fig. 8.1). A particular variant of the experiment occupies the total plot area. If the experiment involves fertilizers, they are applied as prescribed by the experimental procedure. The yield is counted over the accounting area. The latter is smaller than the total plot area because side and end defensive strips are subtracted from it (a double defensive strip is provided between two adjacent plots), and the yield from these strips is not taken into account. The purpose of the defensive strips is to protect the accounting area against extraneous factors and damage: for example, the undesirable influence of the "neighbours" (as is often observed in fertilizer experiments, fertilizers tend to be transferred from one plot to another during their application or soil cultivation, especially in perennial experiments with winter crops) or the so-called edge effect when the plants growing at the plot edges are under more favourable aeration, illumination, and other conditions.

The optimal width of the side defensive strips is 0.5 to 0.75 m for close-growing crops and 1 to 1.5 m for perennial experiments with winter crop, the double defensive strip being 1 to 1.5 and 2 to 3 m wide, respectively. In experiments with row crops, one or two rows on either side of the plot form the defensive strip (two to four rows for the
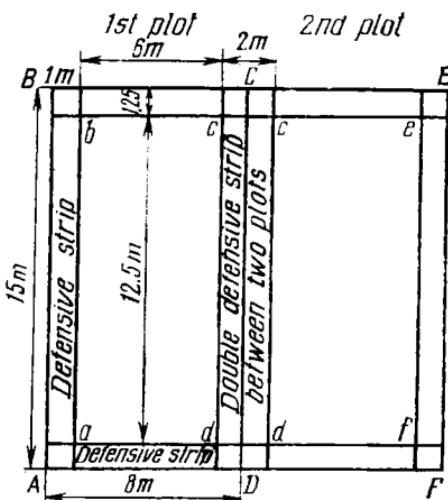
Fig. 8.1. Layout of experimental and accounting plots.

double strip). The end or side defensive strips protect accounting plot areas primarily against accidental damage. Their width is at least 2 to 3 m.

The rational plot configuration ensuring high experimental accuracy may be established on the basis of split yield accounting data. If no reconnaissance sowing with split accounting has been done, the following factors are taken into consideration.

An elongate plot, especially if large, takes better care of irregular soil fertility, reduces the coefficient of variation, and improves the experimental accuracy. If plot fertility varies definitely in one direction, as may be the case when the experiments is carried out on a small slope, the plots must extend along the slope, evenly covering all of its components, otherwise plots located on the upper and lower

parts of the slope will be under entirely different conditions (moisture content, nutrient content, etc.).

Elongate plots must also be used in plot-by-plot cultivation (ploughing, sowing, treatment, harvesting, mechanized fertilizer application). A disadvantage of elongate plots is their long perimeter, and hence, subtraction of sizable chunks of the plot for use as defensive strips and reduction in its accounting area, therefore, the elongate shape makes sense only if the plot size exceeds 50 m², otherwise the edge effect will be difficult to eliminate.

In the case of small sizes (10-20 m²), square plots are more convenient, this configuration diminishing the effect of adjacent variants on the experimental results. The experimental accuracy is increased and the coefficient of variation is reduced by a higher degree of replication.

In plot-by-plot cultivation and in experiments with row crops, the plot width must be multiple to the operating width of farm machines, especially those used for sowing and harvesting, and also to the number of rows for row crops.

The overall layout of the field experiment depends on the configuration and features of the experimental area, its relief, and irregularity of the soil cover. The optimal shape of the total experimental area must be close to square. Here, no matter how the plots are arranged, the spacing between variants is optimal and they are easier to compare.

Being contiguous along their long sides, experimental plots may form one, two, or more tiers. In a two- or multitier arrangement, the number of plot repetitions in each tier must be an integer (Fig. 8.2).

Single-tier arrangement of plots is used in experiments with a small number of variants and replications over an area with a sufficiently regular fertility. In a single-tier pattern, plots are usually elongate and form a right angle with the long side of the experimental area.

Two- and multitier arrangements are most often used when the number of plots is great and they are almost square in shape. However, in such a pattern, bringing similar plots close together both in the vertical and horizontal directions is inadmissible.

Apart from being arranged in a compact manner within

the same experimental area, tiers may also be scattered all over, that is, in different parts of the field or even different crop rotation fields.

The arrangement of plots within tiers may be systematic or randomized.

In the former case, the sequence of plots within each tier follows a certain pattern, for example in series for
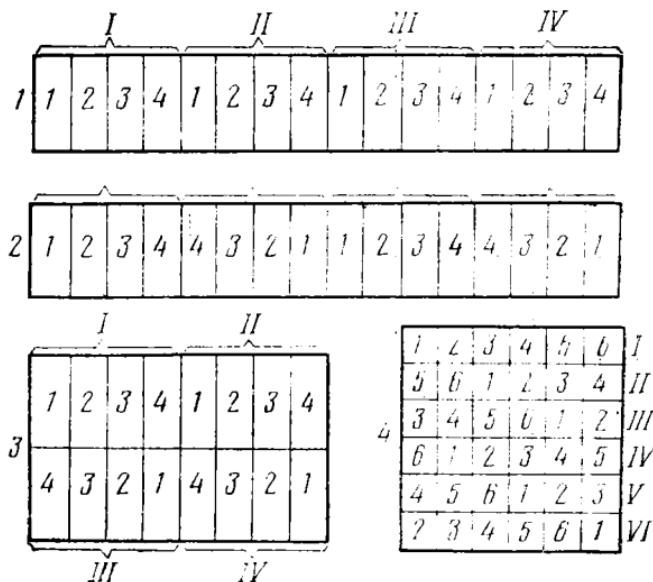
Fig. 8.2. Systematic arrangement of variants

a single-tier arrangement of plots. If multitier arrangement is used, similar plots may be staggered to form a checkerboard pattern.

In a randomized block, plots are arranged at random, either by drawing lots or by using special tables of random numbers, both in a single- and multitier pattern (Fig. 8.3).

Many investigators contend that randomized arrangement of plots (variants) in an experiment more fully covers the irregularity of soil fertility and provides objective information with a more valid systematic processing of the experimental results, in view of the fact that all methods of variation analysis are based on the random selection principle.

Just as any variable factor, control plots are arranged within a block in a randomized or systematic fashion, their number being the same as that of plots with any other variant. However, additional control variants (standards) have been suggested to be introduced into the experimental scheme in order to determine the degree of soil cover irregularity and to obtain more accurate and valid data. With such an approach, the number of control variants is repeated more often

Fig. 8.3. Randomized block pattern

than that of the other variants when the experiment is replicated. This is what is known as the standard method of plot arrangement.

At present, the standard method of plot arrangement is seldom used in experimentation because it is time-consuming, the additional control plots increasing the total experimental area by 40 to 50 per cent. This method has no advantages over the systematic and randomized arrangements when the soil fertility over the experimental area is sufficiently regular.

8.1.4 Schemes of Fertilizer Experiments

The scheme and program of a field experiment are determined by the object of investigation (in fertilizer experiments, the object may be types, forms, rates, and application sched-

ules of fertilizers, nutrient ratios, etc.), that is, by the particular task to be accomplished in the experiment. The experimental scheme represents a combination of variants based on the single difference principle or, in other words, the factor of interest is varied while the rest of the conditions (background) remain identical.

The experimental variants with which the effectiveness of the factor under investigation is compared are known as control variants and, for example, a control without fertilizers is known as pure control.

An important component of an experimental scheme is the background, that is, the identical conditions of plant development, underlying the experiment. It is also important to select the right test plant that would be sensitive to the factor of interest so that the latter could be more widely applied in cultivating the crop in question. In devising an experimental scheme, the necessary number of variants must be such as to give as good an insight into the factor under investigation as possible.

Types of Fertilizers. The simplest scheme of a fertilizer experiment comprises two variants: (1) control (without fertilizer) and (2) variant with a fertilizer. In experiments with fertilizer types, the control variants may be pure control, or background, or pure control plus background.

In determining the effectiveness of certain fertilizers, such as nitrogen, phosphorus, and potassium ones, it is not sufficient to have a scheme comprising four variants, i.e. 1—O, 2—N, 3—P, and 4—K, because the effectiveness of fertilizers often depends on whether they are applied together or singly or on the double minimum, and the appropriate scheme will be: 1—O, 2—N, 3—P, 4—K, 5—NP, 6—NK, 7—PK, and 8—NPK. This octuple scheme based on the orthogonality principle represents all the possible combinations of three types of fertilizers and will provide complete and accurate information as regards the fertilizer effectiveness if all comparison methods are used.

If a fourth fertilizer is introduced into the octuple scheme, the number of variants is doubled, and this scheme will be worthwhile only if the fourth fertilizer, for example lime, is expected to be highly effective. In this case, the octuple scheme will involve limed and unlimed backgrounds and

comprise 16 variants. In other experiments, the fourth type of fertilizer (less effective than lime) can be studied using an optimal variant, such as NPK in an octuple scheme and, therefore, the scheme will include nine variants.

A disadvantage of the orthogonal octuple scheme is that it is cumbersome, which is why it is sometimes simplified. The first way to simplify the octuple scheme is by experimenting with less than three fertilizer types. For example, in an experiment involving only a nitrogen fertilizer, the scheme is simplified and will comprise only four variants: 1—O, 2—N, 3—PK, and 4—NPK. With such a scheme, one can introduce variants with nitrogen fertilizer rates N_2, N_3, and so on, and the scheme will take the following form: 1—O, 2—N, 3—PK, 4—PKN$_1$, 5—PKN$_2$, and 6—PKN$_3$. Another way to simplify the octuple scheme is possible, provided there is no need to separately investigate a nitrogen, phosphorus, or potassium fertilizer. The experimental scheme will then comprise five variants: 1—O, 2—NP, 3—NK, 4—PK, and 5—NPK. If the variant without fertilizer is excluded, we have a four-variant scheme. However, such exclusion is not desirable because the control variant is necessary for a better understanding of the experimental results.

The octuple scheme can also be simplified if the order of the nutrient minimum is known. For instance, if it has been established by agrochemical analysis that a soddy podsolic soil contains nitrogen in the first minimum and phosphorus in the second, the effectiveness of phosphorus and potassium should be studied against the nitrogen background and that of potassium, against the background of nirogen and phosphorus fertilizers. Alternatively, if it is known that a peaty or clover field soil contains much nitrogen, the octuple scheme can be abridged and comprise the following variants: 1—O, 2—P, 3—NK, 4—PK, and 5—NPK. In areas where soils contain much potassium, the effectiveness of fertilizers can be examined using the following scheme: 1—O, 2—N, 3—P, 4—NP, and 5—NPK.

Forms of Fertilizers. Field experiments with fertilizer forms require a great deal of accuracy, uniformity of the experimental area, and a properly selected background. For example, in investigating forms of nitrogen fertilizers, one

must first of all establish the nitrogen requirements of the plants grown in a given experimental area and only then examine the effectiveness of nitrogen fertilizer forms. If it is known that the changes in yield (yield increase), depending on the fertilizer form, will be small, the experiments must be carried out with high accuracy to obtain | valid results.

Experiments with fertilizer forms involve the following control variants: (1) without fertilizer and (2) background. In experiments with a new form (type) of fertilizer, a third variant is added: background plus standard fertilizer applied at one or several rates. This will permit determining the sensitivity of the test plant to changes in the amount of the available nutrient in the fertilizers.

Sokolov has proposed the following scheme for experiments with new forms of fertilizers: (1) without fertilizer (control), (2) basal fertilizer—background (control), (3) basal fertilizer plus half the standard fertilizer rate, (4) basal fertilizer plus three quarters of the standard fertilizer rate, (5) basal fertilizer plus standard fertilizer applied at full rate, (6) basal fertilizer plus the first fertilizer under investigation, applied at full rate, (7) basal fertilizer plus the second fertilizer under investigation, applied at full rate, and so on.

In view of their physiological acidity and alkalinity, nitrogen fertilizer forms should be studied against two backgrounds: limed and unlimed.

To study the effectiveness of fertilizer forms, one must establish the correct rate of their application because at high rates the differences between fertilizer forms under test are not distinguishable. Sokolov and Yudin have proposed the following schemes of field experiments involving the effectiveness of high-analysis and compound fertilizers.

Scheme of Experiments with Compound Fertilizers

(1) without fertilizer or background;

(2) compound fertilizer;

(3) equivalent amounts of single standard fertilizers;

(4) compound fertilizer + single standard fertilizer to achieve normal nutrient rates;

(5) single standard fertilizer at normal rates.

Scheme of Experiments with High-Analysis Fertilizers*
(1) control (without fertilizer);
(2) NPK (a mixture of simple fertilizers: ammonium nitrate, ordinary superphosphate, potassium chloride);
(3) NPK (a mixture of high-analysis fertilizer: usea, double superphosphate, potassium chloride);
(4) ammophos + NK (a mixture of simple fertilizers);
(5) double superphosphate + NK (a mixture of simple fertilizers).

These schemes permit the effectiveness of compound and high-analysis fertilizers to be determined in comparison with single fertilizers and the optimal nutrient ratio in compound fertilizers to be established with respect to a given crop and soil conditions.

Fertiliser Rate. In experiments aimed at elucidating fertilizer rates, it is important to define the interval between rates. The interval must be sufficiently broad for yield increments due to the neighbouring rates (which may range in number from three to four) to be distinguishable by a value exceeding the experimental error, that is, the experimental results must be quite valid. Control variants in such experiments include those without fertilizers or a properly selected optimal background, which will permit establishing the absolute yield increase due to the fertilizer rate under investigation and deriving a curve of yield increases with the fertilizer rates.

The scheme of an experiment with fertilizer rates may be as follows: (1) background (PK); (2) background + half the rate; (3) background + N at full rate; (4) background + N at one and a half rate; and (5) background + N at three rates.

The experiments may help to establish the rate providing for the highest yield, the rate at which the yield return is maximum, and the most economical rate.

The optimal fertilizer rate is a relative quantity depending on a host of factors. For example, it may differ depending on whether irrigation is used or not, and so on. Hence, the effectiveness of fertilizer rates is largely dependent on the

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* In this scheme, nitrogen, phosphorus, and potassium rates are equivalent to the second variant.

background. It is therefore natural that experiments with fertilizer rates eventually become investigations of the nutrient ratio under a given set of conditions.

Studying fertilizer rates and nutrient ratios in field experiments based on an orthogonal scheme, that is, when all its variants are represented at each replication and each variant finds itself in all replications, would render the experiment too cumbersome (64-72 variants), therefore, the optimal ratio, for example N : P or N : P : K, should better be examined using a scheme composed of blocks or links and proposed by Sokolov:

A	B	C
1. Control (no fertilizer)	1. Control (no fertilizer)	1. Control (no fertilizer)
2. $P_{90}K_{90}$	2. $N_{90}K_{90}$	2. $N_{90}P_{90}$
3. $P_{90}K_{90} + N_{60}$	3. $N_{90}K_{90} + P_{60}$	3. $N_{90}P_{90} + K_{60}$
4. $P_{90}K_{90} + N_{90}$	4. $N_{90}K_{90} + P_{90}$	4. $N_{90}P_{90} + K_{90}$
5. $P_{90}K_{90} + N_{120}$	5. $N_{90}K_{90} + P_{120}$	5. $N_{90}P_{90} + K_{120}$
	6. $N_{90}K_{90} + P_{180}$	

Thus, one can determine from field experiments the optimal fertilizer rates and nutrient ratios, refine the critical indicators of laboratory methods for determining the mobile forms of nutrients as a function of specific soil and farming conditions, and elucidate the nutrient requirements of various farm crops.

Fertilizer Application Techniques. The optimal fertilizer application schedules and techniques are a major factor of high fertilizer effectiveness. The control variants in experiments with fertilizer application techniques include (1) variant without fertilizers or background and (2) variant with fertilizers applied by a standard technique.

Comparison with the first variant is indicative of the effectiveness of the fertilizer itself under given conditions, while the second permits determining the effectiveness of the new application technique. Experiments with new fertilizer application techniques should also include control variants (without fertilizer) but with additional soil tillage associated with incorporation of fertilizers by the new technique.

The overall rate of all nutrients in examining fertilizer application techniques must remain the same irrespective of the experimental variants (except for those without fer-

tilizer). If, for example, N is added to the overall annual rate
to be used for dressing, the scheme must include a variant
with nitrogen dressing but without an additional increase
in the overall rate. The fertilizer rates for each application
technique must be optimal because some techniques are ef-
fective only at a particular rate (e.g. localized applications).

Schemes of Complex, or Multifactorial, Experiments.
Complex, or multifactorial, experiments are carried out to
investigate the effect of various fertilizers at different rates
and also the effect of fertilizers in combination with other
farming procedures (irrigation rates, crop varieties, culti-
vation techniques, various alternations in crop rotations,
etc.).

The joint application of different procedures studied in the
experiment gives rise to additional effects resulting from
interaction between two or more factors under investigation.
The control variants in multifactorial experiments include
those without fertilizer against all kinds of agricultural
backgrounds and all variants with the fertilizer of interest
against a background adopted as standard.

A scheme of multifactorial experiments may be based on
the orthogonality principle, that is, complete factorial ex-
perimentation in which every level of a factor is combined
with all levels of the rest of the factors, that is, all possible
combinations of factor levels under examination are tried.

The multifactorial experiment is exemplified by the clas-
sical octuple scheme where three factors N, P, and K are
studied at two levels: 0 and 1. The scheme of such an experi-
ment can be written as $2 \cdot 2 \cdot 2 = 8$, if three factors are stud-
ied at three levels, the scheme takes the form $3 \cdot 3 \cdot 3$ and
includes 27 variants; if four levels are taken $(4 \cdot 4 \cdot 4)$, the
number of variants increases to 64 and at five levels $(5 \cdot 5 \cdot 5)$,
to 125; in other words, the number of variants steadily in-
creases with that of levels. Field experimentation with such
a number of variants becomes impossible, therefore, the
multifactorial experiment scheme may be based on a samp-
ling principle or a synthetic experiment which is an abrid-
ged version of the multifactorial one and uniformly covers
the entire range of the increasing fertilizer under examina-
tion. However, such a departure from the orthogonality
principle lowers the validity of the results.

A special notation of variants is used in a multifactorial experiment; for example, in fertilizer experiments, the symbols N, P, and K are replaced by numerals standing for rates in conventional units. For instance, variant NP_3K_2 (1-3-2 being the fertilizer rates) is written as 132, variant $N_3P_4K_2$ is written as 342, and so on.

The laboratory of methods for studying and predicting the effectiveness of fertilizers at the USSR Research Institute of Fertilizers and Agronomical Soil Science recommends arranging variants in blocks within replications. For example, the experimental scheme $3 \cdot 3 \cdot 3 = 27$ will be arranged in three blocks:

```
Block 1  102  012  210  111  120  201  000  222  021
Block 2  101  002  122  110  011  020  212  221  200
Block 3  220  211  010  121  202  112  100  001  022
```

These blocks differ in the composition of the constituent variants but are uniform within the effects of three factors and their interactions in pairs. The sum of levels of each factor is also the same in all blocks. Depending on the structure of the experimental scheme, arrangement in blocks can proceed in one or two directions, which permits the irregularity of soil cover to be taken into account either in one or in two directions (line blocks in the horizontal direction and column blocks in the vertical).

8.1.5 Field Experimentation Schedule

Another major step apart from preparing the scheme of an experiment is drafting its schedule which must incorporate both agrotechnical factors (experiment establishment procedure, calculation of fertilizer rates, time and technique of their application, sowing, maintenance of the experiment, etc.) and the associated observations and studies, both qualitative (visual) and quantitative factors (phenological, meteorological, phytopathological, and entomological observations, analysis of soil and agrochemical conditions, associated analyses of plants and soils, methods and components of yield accounting, etc.).

The experimental schedule includes a detailed description of all experimentation conditions essential for accomplish-

ing the tasks involved and obtaining accurate and valid results.

Depending on the objects and aims of experimentation, the test crop, and other conditions, the schedule of field experiments with fertilizers must include observations and monitoring of plant nutrition conditions which permit assessing the effect of the factor of interest on the import and export of the basic nutrients, such as N, P_2O_5, K_2O, CaO, MgO, B, Cu, Mo, Mn, Sn, Co, and others, as well as determining the effect of this factor on crop yields and quality (contents of proteins, fats, sugars, starch, vitamins, etc.).

Plant samples are taken and examined both dynamically, that is, throughout the vegetation period, and in the final yield, the analysis data being used to determine the rates of vegetable matter accumulation in the crop and to establish the biological and crop removal of nutrients.

Plant sampling is done at the main stages of crop development or following a fixed schedule (e.g. every decade) from a definite area or a certain number of plants (in the case of widely spaced crops).

Soil samples are taken before establishing the field experiment, and the results of soil analysis are used to characterize agrochemically the experimental area and to select the right time for experimentation. Soil samples are also taken in the course of the experiment to estimate the effect of the variable factor on the agrochemical and agrophysical properties of the soil.

To avoid systematic errors and to make the sampling as representative as possible, the soil should be sampled by the randomization method which, as was noted by Dospekhov, "eliminates bias of the estimate, substantially improves the quality of data, and permits the experimenter to apply statistical methods of data processing more reliably."

The number of individual soil samplings for a mixed sample from an experimental plot depends on the degree of variation of the main objects of observation under the experimental conditions. The department of farming and experimental methods at the Timiryazev Agricultural Academy in Moscow recommends six to eight samplings for the mixed sample from a plot less than 100 m² in size, the number of samples taken from a plot 100 to 200 m² in size being eight

to twelve and that of samples taken from plots larger than 200 m² ranging from fifteen to twenty. Soil samples are taken with the aid of an auger, the core usually being as long as the arable layer is deep. However, depending on the program of investigation, individual soil samples are taken from different horizons of the soil profile. Soil pits should be confined within the experimental area.

8.1.6 Carrying Out a Field Experiment with Fertilizers

Strict adherence to appropriate methods is a prerequisite for obtaining accurate results necessary to objectively assess the factor under investigation.

After the experimental area has been prepared for the field experiment, a layout is drafted showing plots and their tiers as well as the selected configuration and size of the plots (experimental and record ones). Two adjacent plots with a double defensive strip in between are drawn at a larger scale also indicating the end and side strips.

The total area of the experiment, including the defensive strip around it, is determined and entered in the record.

The boundary of the experimental area is defined, drawn on the layout and entered in the record along with the permanent bench mark or some other reference point.

The layout is then traced at full scale on the experimental area with strict adherence to the experimental procedure. To this end, the long margin of the experimental area is staked out using five to ten poles 1.5 to 2 m long. The poles must be straight, coloured red or in stripes for better visibility. A cord may also be used to stake out the long margins. Angular instruments (mirror square, theodolite, etc.) are used to construct a perpendicular to the long margin, and the short margin is staked out.

The second long margin is staked out in a similar manner.

The opposite margins of the experimental area must be equal in length if the right angle has been set off correctly. The misclosure of the total outline should not exceed 5 to 10 cm per 100 m of length, otherwise (>10 cm) the boundaries should be retraced.

A metal measuring tape or reel is used to set the width of an experimental plot off the long margin, and a peg (25-

30 cm high, 3-4 cm in diameter) is driven into the ground at the appropriate point. The number of such pegs must exceed the doubled number of plots by 10 to 15. The pegs are inserted at the corresponding mark of the measuring tape. The boundaries of plots are marked by two pegs. All the legends on the pegs are written on the side facing the respective plot. The plots must be strictly rectangular in shape.

After the experimental area has been laid out, its principal boundaries are marked, that is, the experiment is tied in to the terrain, because the pegs are removed before fertilizers are incorporated (ploughing, cultivation, etc.), and without boundary markers it is impossible to reconstruct the field experiment at full scale. While tying in, the principal boundaries of the experimental area (at least two) are extended beyond the area to be cultivated, and permanent bench marks are placed at their ends. The distance between the reference point (bench mark) and the corner of the experimental area is measured, entered in the record, and plotted on the schematic of the field experiment so that the boundaries could be retraced if necessary.

The accounting areas and defensive strips between them should preferably be traced after sprouting, in the case of close-growing crops (cereals, pulses, flax, grasses). To this end, a cord is stretched along the long margin at a distance of 0.5 to 1 m from the edge, and strips 15 to 20 cm wide are made immediately outside the accounting area. Similarly, end strips are made at a distance of 2 to 3 m.

In the case of row crops, defensive strips are not made in advance; they are formed during harvesting by leaving aside one or two rows along the edges and two to four rows between adjacent plots on which the crop yield is not taken into account.

The most important components of establishing a field experiment are calculation of fertilizer rates and their application to the experimental plots. The validity of the experiment depends on how correctly and accurately this has been done, because it is impossible to eliminate the errors made in the calculations and establishment of the experiment, these errors being even difficult to notice.

According to the experimental scheme, inorganic fertilizers are calculated from the content of the basic nutrient in

them (N, P_2O_5, K_2O), in kg per plot, using the formula:

$$X = \frac{ac}{100\,b}$$

where X is the amount of fertilizers to be applied per plot (kg), a is the rate of the nutrient in the fertilizer to be applied (kg/ha), b is the content of the active ingredient in the fertilizer (%), and c is the size of the experimental plot (m^2).

Amounts less than 1 kg are weighed to within 1 g, those from 1 to 10 kg are weighed to within 10 g, and amounts exceeding 10 kg are weighed to within 100 g.

All fertilizers must be thoroughly ground and sifted before weighing. Fertilizers are weighed both in laboratory and in the field. Then, according to the application schedule, fertilizers are broadcast by machines or by hand. If a plot is to receive several types of fertilizers, they can be mixed before incorporation or applied separately. The broadcasting is performed on a quiet windless day with the fertilizers being evenly distributed over the plot area. Sowing and planting in the experimental area involves top quality seeds spread over all plots on the same day. A 4- to 6-h interval in the sowing of early spring crops reduces the yield by one to two centners per hectare.

The sowing rate must be correlated with the number of seeds rather than their weight because in different years of experimentation seeds may differ in size, which may lead to different stand densities on a plot.

Rows of close-growing crops must extend across plots, along the long margin of the experimental area. Row crops are usually planted along the long side of the experimental plot with the rows or the operating width being multiple to the plot width. However, even in the case of row crops, it is better (if the scheme allows) to arrange rows at a right angle to the long sides of the plot or, in other words, along the long margin of the experimental area.

Throughout their vegetation period, plants grown in the experimental area require the same care as under actual farming conditions except that this care should be exercised with greater deliberation and simultaneously on all plots.

All the cultivation procedures involved in carrying out the experiment (except for the factor under investigation)

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should be performed simultaneously, with high quality, and against an agricultural background optimal for the experiment. Departure from the single difference principle and typicalness may render the experiment less valid in essence.

The special procedures to be performed in an experimental area include (after close-growing crops have sprouted) making the defensive strips and tracing the accounting areas of experimental plots, trimming the ends of experimental fields, and placing labels identifying the experiment and smaller ones bearing the number of the plot and the name of the variant.

Two to three days before harvesting, the boundaries of record plots are restored, each plot is carefully examined, and, if necessary, some parts of the plot are excluded from the experiment, measured, plotted on the layout, and their size is entered in the record. The exclusion affects the record plot and is done if some accidental damage or errors have occurred during experimentation. The exclusions must be done so that account would be made only of the yield typical for a given variant to permit objective assessment of the effect of the factor of interest.

The excluded area should not exceed 50 per cent of the accounting area, otherwise the entire plot is rejected. The defensive strips and excluded areas are harvested first, the yield from these parts of the experimental area not being taken into account, then the rest of the yield is harvested and counted.

In experimentation practice, there are two methods of yield counting: direct and indirect. The direct, or overall, counting method involves harvesting and weighing the yield from the entire accounting area of the plot. Wide recognition has been gained in recent years by straight combining using a small self-propelled combine, or harvester. In this case, the width of the record plot must be multiple to the operating width of the combine, the plot being preferably elongate. If grain crops are harvested in a different manner (using sickles or cradles), the self-propelled combine can be used to thrash sheaves, which permits optimizing the combine operation and minimizing its idle time between harvesting of two plots (3-4 min). The grain is sampled for determination of its moisture content and for the yield to be recal-

culated to standard 14% moisture content. Row crops are harvested and counted in this fashion. If roots or tubers are dirty, a correction factor is introduced to take care of the earch clinging to them.

In indirect yield counting (test sheaf method), the accounting area is harvested completely, and the total fresh weight is determined just as in direct counting. Then, two test sheaves (cereals, pulses, grasses) are taken from each record plot, each weighing 4 to 5 kg (up to 15 kg if the harvested

Table 8.1. Direct Counting Record Form

Plot No.	Variant No.	Accounting area (m²)	Yield from plot (kg)			Yield (cent/ha)		
			total	grain	straw	total	grain	straw

crop is flax), which are dried, thrashed, and the total and grain (seed) weights are determined (cereals and pulses).

All results of yield counting by either method are entered in the field experiment record and the numerical data undergo preliminary processing (Tables 8.1 and 8.2).

Table 8.2. Indirect Counting Record Form

Plot No.	Variant No.	Accounting area (m²)	Fresh yield (kg)		Ratio of overall plot yield to test sheaf weight	Weight of dry test sheaf (kg)			Yield from plot (kg)			Yield (cent/ha)		
			from entire plot	in test sheaf		total	grain	straw	total	grain	straw	total	grain	straw

During harvesting, samples are taken from the main and by-products yielded by each variant to assess their quality.

All other yield counting methods (test plot, individual plants) involve reduction in the accounting area, lower the experimental accuracy, and are otherwise ill-suited for experimentation purposes.

8.1.7 Farm Experiments and Estimation of Fertilizer Effectiveness Under Actual Farming Conditions

Many collective and state farms provide their facilities for integrated research activities aimed at broader implementation of advances in science and agriculture. Such activi-

ties include preliminary trials of the new procedures and techniques for raising crop yields, recommended by research institutions, whose effectiveness is to a great degree dependent on local natural conditions as well as farming and managerial practices.

Farm experiments give an insight as to the best and most complete implementation of scientific achievements in agricultural production and permit not only optimizing the farming procedures, but also assessing their economic effectiveness.

For the experimental results to be objective, the farm experiment must meet the methodological requirements imposed on field experimentation. Failure to meet these requirements may detract from the objectivity of assessment of the effectiveness of the factor under investigation. Setting up and carrying out a farm experiment involves some special methods determined by the nature of the investigation, natural and farming conditions, the availability of the necessary materials and machinery, type of experiment, and other factors. This is why there is no established standard procedure for farm experimentation, each method being prompted by the conditions prevailing at a given farm.

It is advisable, for example, to provide for a greater number of variants (4-5 and more) and replications (3-4 and more) in a farm experiment. It is extremely important that all experimental procedures be mechanized as much as possible so as to carry them out at the same time according to schedule.

Some workers recommend carrying out farm experiments over large areas (up to 10-20 ha and more), however, such enlargement of the experimental areas is not always justified and sometimes gives rise to serious errors. The main reason why this happens is that variants occupying large areas may involve appreciable soil irregularity, whereby the principle of single difference is upset. Therefore, the information about the effectiveness of the factor under investigation will be distorted and, consequently, the conclusions drawn from such experiments may be wrong. Moreover, farm experiments over large areas are time- and labour-consuming, hence, flexibility should be exercised in selecting the size of the experimental area which must be optimal for each particular case,

and the experimental schedule must include a minimum of the necessary observations and investigations.

The next step in farm experimentation is assessment of the fertilizer effectiveness under actual farming conditions. To this end, when a new procedure is introduced (type of fertilizer, application rates, times or techniques, etc.) into standard farming practice which normally involves large areas, three to four untreated strips are put aside in crop rotation and other fields of collective and state farms to serve as control or record plots. The yields from these plots are compared with that from the fertilized field where the new procedure is tested.

Some manuals recommend that the control strips be located closer to the field edge or roads with the yields from these strips being compared with that from the entire fertilized field. Methodologically this is wrong because, firstly, comparison with different degrees of accuracy is inadmissible (the treated field and untreated strip being different in extent) and, secondly, plants grown on the control strip extending closer to the field edge or road develop under conditions differing from those governing the development of plants in the middle of the field. Therefore, the control strips must be evenly distributed over typical field parcels covering the entire diversity of the farmland, the strips extending across the whole field along the path of fertilizer drills and harvesters, at a distance of 20 to 30 m from the field edge. The size of a control strip should not exceed 0.1 to 0.25 ha and is the product of the multiple to the number of harvester passes (but not less than two passes) and the length of furrow. The accounting strip margins are staked out and the boundaries are marked distinctly to avoid errors when the yield is counted.

Before harvesting, fertilized strips are provided next to the control one (sometimes on either side of the control strip), which must extend across the entire field, parallel to the control strip. The number of control and fertilized strips and their sizes must be strictly equal, and they must be harvested at the same time.

The yields from control and fertilized strips are counted by the direct or indirect method. Just as in a stationary experiment, the defensive strips are harvested first. When

the control and fertilized strips are harvested, plant samples are taken for agrochemical analysis.

Table 8.3. Form of Record Used in Farming Procedure Evaluation Under Local Farming Conditions (according to Dospekhov)

Experimental conditions	Bulk grain yield					Grain dock-age (%)	Mois-ture con-tent in grain (%)	Grain yield at standard moisture content (cent/ha)
	first strip	second strip	first strip	second strip	ave-rage			
	kg per accoun-ting strip 800 m²		cent/ha					
Without fertilizer	96.0	144.0	12.0	18.0	15.0	5.5	15.5	14.4
With fertil-izer	131.3	189.7	[16.4	23.7	20.0	3.8	16.0	18.6

For the results of assessment of fertilizer effectiveness to be objective, the experimental data undergo mathematical processing, and an exact agrochemical and economical esti-mate is made of the effectiveness of the newly introduced procedure under local conditions.

8.2 Greenhouse Experiments

Greenhouse experimentation with fertilizers is carried out in an artificial environment, in pots, with a view to studying the nutrition of plants and their metabolism in the pots. Just as field experiments, greenhouse ones form part of biological research. They elucidate different aspects of plant nutrition, permit evaluating the assimilation of fer-tilizer nutrients by plants, and give an insight into soil fer-tility, that is, greenhouse experiments expose the cycle of nutrients in agriculture along the lines proposed by Prya-nishnikov: plant nutrition, soil and fertilizer properties.

Greenhouse experiments are conducted to study the nutri-tion of various farm crops, to explore the possibility of con-trolling nutrition conditions, and to provide the theoretical basis for procedures aimed at increasing crop yields and quality. They have made it possible to establish the macro-

and micronutrients necessary for plants, the forms and types of compounds of these nutrients assimilable by plants, the importance of the symbiosis of nodule bacteria with legumes in fixing atmospheric nitrogen, and many other things.

Depending on the objectives and tasks to be accomplished, plants in a greenhouse experiment may be grown for several days or till they reach full maturity, the growth period being as long as several years in perennial experiments.
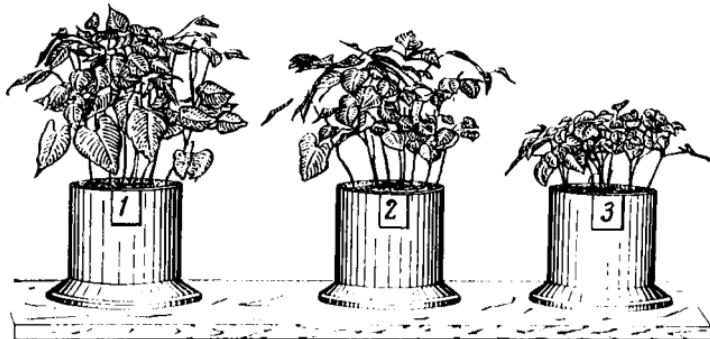
Fig. 8.4. Kidney bean plants in vegetative pots:
1—slag, *2*—lime, *3*—control

As the name implies, such experiments are carried out in greenhouses where plants are grown in special vegetative pots also known as Mitscherlich pots (Fig. 8.4).

To obtain a fuller picture of plant nutrition and the effect of fertilizers on it, greenhouse experiments have a number of modifications, including soil, sand, and water cultures, the isolated nutrition method, flowing solutions, sterile cultures, and so on, which permit a finer distinction to be made between plant responses to different effects and between impacts of different factors on plant growth and development.

Soil Cultures. Soil cultures play an important role in greenhouse experiments aimed at studying the interactions in the plant-fertilizer-soil system. In retrospect, greenhouse experiments with soil culture were prompted by the desire to avoid irregular soil fertility.

The soil for the experiment is taken from the arable layer and is thoroughly mixed in all pots, to achieve uniformity, then passed through a sieve with holes 3 mm in diameter,

which ensures consistency of the experimental results from similar pots when the experiment is replicated.

Greenhouse experiments involve the topsoil in most cases, which accounts for the plants receiving much less nutrients from the soil, as compared to natural conditions under which they receive a large quantity of nutrients not only from the topsoil but also from the subsurface and deeper layers.

In greenhouse experiments, plants are less exposed to unfavourable weather conditions, such as insufficient or excessive moisture, because they are watered in a controlled manner as prescribed by the experimental procedure. Of all greenhouse cultures, soil ones are the closest to natural conditions and field experiments. However, the results of greenhouse experiments cannot be directly implemented in farming practice because, unlike field experiments, those conducted in greenhouses give qualitative rather than quantitative estimates of the factor under investigation and although they permit establishing the effectiveness of the factor, it is impossible to predict the amount of yield increase under field conditions.

It is useless to create the same conditions in greenhouse experiments as in field ones; what has to be done is to provide equal conditions in all pots, eliminate adverse effects, and optimize the combination of growth factors (temperature, light, moisture, etc.).

In greenhouse experiments, the following average fertilizer rates (in g) are recommended for pots containing 5 to 8 kg of soil: N, 0.35 0.75 and more; P_2O_5, 0.3-1.0; K_2O, 0.3-1.0. The fertilizer rates for a soil culture are also calculated per kg of dry soil (in g): N, 0.05-0.20; P_2O_5, 0.05-1.15; K_2O, 0.05-0.2.

The fertilizer rates recommended by Zhurbitsky are listed in Table 8.4.

Greenhouse experimentation provides optimal conditions for plants, and the effect of the factor under investigation is so well pronounced that the experimenter is offered an ideal opportunity to study a wide range of individual factors.

Greenhouse Experiment Procedure. Since no systematic error is involved and equal soil conditions are created in all pots, greenhouse experiments permit a more detailed analysis of the factor of interest, therefore, such experiments may

Table 8.4. Fertilizer Rates (g nutrients per kg of soil) in Greenhouse
Experiments with Soil Cultures

Crop	N	P_2O_5	K_2O
Cereals	0.15	0.10	0.10
Legumes	0.10-0.15	0.10-0.15	0.10-0.15
	(0.02-0.04)*		
Potato	0.12	0.20	0.28
Sugar beet	0.15	0.22	0.22
Flax	0.05-0.07	0.10-0.12	0.06-0.1
Hemp	0.20-0.30	0.20-0.30	0.20-0.30
Cotton**	0.24	0.36	0.06-0.09
Tobacco	0.20-0.30	0.10-0.20	0.20-0.30
Vegetables:			
cabbage	0.15-0.20	0.20-0.25	0.20-0.25
tomato	0.10-0.15	0.15-0.20	0.20-0.35
cucumber	0.15-0.20	0.15-0.20	0.20-0.25
table beet	0.15-0.20	0.20-0.25	0.20-0.25
carrot	0.15-0.20	0.20-0.25	0.20-0.25
onion	0.10-0.15	0.10-0.15	0.15-0.20

* In experiments involving enrichment of the soil with nitrogen fixed by
legumes.
** Grown on calcareous sierozems.

often be multivariant. Depending on the experimental pro-
gram and test crops (cereals, flax, grasses or row crops such
as potato, beet, and maize) greenhouse experiments may be
replicated two to four or six to eight times.

Before a greenhouse experiment is established, the neces-
sary soil distribution pattern is determined, and a plot
typical of this pattern is selected. In spring, when the soil
becomes "mature", that is, when it is not smeary and its
lumps readily crumble, the topsoil is taken from this plot
(if the plot is covered with sod, the latter is removed and
thrown away).

In summer, the soil-derived nitrogen is nitrified and the
soluble phosphates are immobilized, therefore, the soil tak-
en for greenhouse experimentation in summer is less respon-
sive to nitrogen and slightly more responsive to phosphorus.

A composite sample is taken from the detached soil for
agrochemical analysis (before the experiment is established).
Also determined are the moisture content and water capaci-

ty of this soil to determine how much absolutely dry soil is
to be put into the pot, and the water requirements are defined.
All data are entered in the greenhouse experiment record.

Experiments with both soil and sand cultures are con-
ducted in pots (made of glass, metals, or plastics).

The pot size is a major factor determining the amount of
yield: it has been established that for grain crops, flax, pea,
and buckwheat pots 15×20 and 20×20 cm in size are
required, the pot size for plants with deep roots, such as clo-
ver and alfalfa, is 15×30 cm, and the optimum for row
crops, such as potatoes, beets, maize, and sunflower, is $25 \times
\times 30$ and 30×30 cm. Pots of these sizes contain 5-7 to
12-14 kg of soil and even more, however, depending on the
experimental task, pots containing 1 to 3 kg of soil (sand)
may also be used.

Prior to experimentation, the pots are selected by volume
(height and diameter), glass and plastic pots are calibrated
by crushed glass (200-300 g per pot) which also serves as
drainage.

The drainage glass is placed to cover two thirds of the pot
bottom at an angle of $30°$, covered with a round piece of
gauze, whose diameter exceeds that of the pot by 3 to 5 cm,
and a watering glass tube is inserted into the mound of glass,
vertically, at a distance of 1.5 to 2 cm from the pot wall
(during packing).

Moist sand is smeared over the round piece of gauze (45-
75 ml of water are added to 300-500 g of sand), and the pot
is packed. The first pot to be packed is used as control.

The necessary amount of soil is weighed, and the pot is
packed tentatively so that the soil stops 2 to 2.5 cm short
of the pot rim for the remaining space to accommodate sand
and be used for watering from top. If the soil level is below
or above the desired mark after tentative packing, its amount
should be adjusted accordingly. All pots must contain
strictly equal amounts of soil.

Greenhouse experiments involve fertilizers and pure salts
with a minimum amount of deal weight. Water-soluble (ni-
trogen and potassium) fertilizers are used in solution (about
1 g nutrient per 100-50 ml of water), while insoluble
(phosphorus and lime) ones are added dry.

Application of fertilizers in solution calls for the same

moisture content in all pots, without waterlogging the soil. The optimal moisture content in packed pots is 40 to 50 per cent of the total water capacity.

Fertilizers are evenly distributed in the weighed portion of soil and intimately mixed with the latter. The first soil portions (3-4 cm) are carefully charged into pots and compacted there. For the compaction to be uniform, all pots in an experiment should preferably be packed by the same person.

Used for experiments are high-quality pure-strain seeds with a high germinating ability. The seeds are selected, treated with a 1% formalin solution, washed with water, and allowed to germinate. To this end, troughs are filled with sand which is covered with filtre paper, the seeds are moistened evenly, spread in a thin layer, and covered with a double layer of wetted filtre paper or a sheet of glass to minimize water evaporation. The seed germination temperature varies from 20 to 25 °C.

Sprouted seeds are sown through a template to a depth of 0.5, 2, 5, or 6 cm depending on the crop and seed size.

The number of plants after sprouting must be the same in every pot. In a pot 15 cm in diameter it is recommended to leave 20 to 25 cereal plants, 10 to 15 pea plants, 10 to 12 buckwheat plants, 35 to 40 flax plants, and 6 to 12 clover plants.

Row crops are grown in large pots with a single plant being left in each pot by the end of the harvesting time. To improve the experimental accuracy, the number of replications is increased.

Small-seed crops with known germinating ability are often sown with dry seeds. To do this, the top layer (0.3-0.5 cm) of the soil is removed, the necessary quantity of seeds is evenly spread over the surface and covered by the removed soil, then a layer (200-300 g per pot) of quartz sand is placed on top to prevent evaporation of water from the soil as well as crust and crack formation. For the sprouting to be simultaneous, the pots are covered with a sheet of cardboard or paper or with trays.

Depending on the experimental schedule, the plants are irrigated with tap, distilled, or twice-distilled water, usually in the morning.

Glass and plastic pots are watered according to a precalculated rate. An optimal moisture content is maintained at the same level in all pots (60-80% of the total water capacity).

On hot days especially if the plant is bulky, the watering is done twice (in the morning and in the evening), one rate being based on weight and the other, on volume. Sometimes, the watering rate is adjusted with respect to the plant weight, whereby more water is used.

Mitscherlich pots (covered with netting) are watered to the brim.

When the plants reach maturity and to speed up the latter, they are watered less frequently and at lower rates.

In the course of vegetation, when the weather is good, the pots with plants are carted out of the greenhouse in which they remain in rainy weather and for the night.

Uniform illumination and heating are achieved by rearranging the pots on carts and racks, during watering, in a definite pattern. To avoid lodging of the plants, they are supported in pots by wooden or wire frames.

The plants are harvested before reaching full maturity. After drying in special bags, the total weight of the plants is determined along with that of seeds after thrashing, the weight of straw and chaff being determined by difference.

Plant and soil samples are taken for analysis. If the experimental procedure involves roots and their analysis, the roots are separated from the soil by repeated washing, the final washing being done on a sieve with 0.5 mm mesh, using tap and distilled water, then they are dried, weighed, and prepared for analysis.

The preliminary processing of the results of greenhouse experiments is done similarly as in field experimentation.

Sand and Water Cultures. In such nutrient-free media as water and sand, plant nutrition is studied under closely monitored conditions.

To investigate plant nutrition in an artificial sterile medium (water or sand culture), use is made of nutrient mixtures containing nutrients in amounts and at ratios necessary for normal plant growth and development (Table 8.5).

Mixtures of properly selected nutrients differ in salt composition and, primarily, sources of nitrogen and phosphorus

Table 8.5. Nutrient Mixtures for Water and Sand Cultures
(mg/litre of water or kg of sand)

Mixture	Hellrie-gel's	Knop's	Prya-nish-nikov's	Belousov's (for sugar beet)	Yagodin's (for buck-wheat)
$Ca(NO_3)_2$, anhydrous	492	1000	—	1100	—
NH_4NO_3	—	—	240	—	343
KH_2PO_4	136	250	—	360	263
K_2HPO_4	—	—	—	430	—
K_2SO_4	—	—	—	—	166
$Fe_2(SO_4)_3 \cdot 9H_2O$	—	—	—	—	40
$CaHPO_4 \cdot 2H_2O$	—	—	172	—	—
$MgSO_4$, anhydrous	60	250	60	54	—
$MgSO_4 \cdot 7H_2O$	—	—	—	—	716
KCl	75	120	160	—	—
$FeCl_3$	25	traces	25	10	—
NaCl	—	—	—	100	—
H_3BO_3	—	—	—	5	2.86
$CaSO_4 \cdot 2H_2O$	—	—	344	—	—
$CuSO_4 \cdot 5H_2O$	—	—	—	—	0.197
$ZnSO_4 \cdot 7H_2O$	—	—	—	—	0.44
$MnSO_4 \cdot 5H_2O$	—	—	—	5	2.63
$CoSO_4 \cdot 7H_2O$	—	—	—	—	0.095
$Na_2MoO_4 \cdot 2H_2O$	—	—	—	—	0.077
$CaCO_3$	—	—	—	—	500.5
$CaCO_3$ (applied additionally after 20 days)	—	—	—	—	55.5

nutrition, which must be balanced in the mixture to provide for the right pH of the medium.

Nutrient mixtures should meet the following requirements: (1) A mixture must include all the necessary nutrients for a particular crop. If a nutrient is missing, plants will not develop normally because no substitution for the missing nutrient is possible. (2) Nutrients in a normal mixture used as standard nutrient solution must be in an available form. It is not possible, for example, to include sulphides as sources of sulphur. (3) Nutrient must be applied in amounts and at ratios ensuring high crop yields. (4) pH of the medium must be optimal or close to optimal throughout the vegetation period.

Knop's and Hellriegel's nutrient mixtures have been developed in an empirical fashion.

Pryanishnikov's nutrient mixture has resulted from theo-

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retical studies. By proper selection of nitrogen and phosphorus nutrition sources, the scientist brought the initial reaction of the medium close to neutral, and it was maintained at this level throughout the experiment. Development of this mixture was based on the capacity of various plants to take up phosphoric acid from poorly soluble phosphates. The resulting nutrient mixture did not alkalize the medium throughout the vegetation period because the buffering effect of the constituent salts had been taken into consideration.

Phosphates produce a buffering effect on both acidulation and alkalinization. Monosubstituted phosphates (KH_2PO_4, NaH_2PO_4, etc.) are buffers against alkalinization, while disubstituted ones (K_2HPO_4, Na_2HPO_4, $CaHPO_4$) and $Ca_3(PO_4)_2$ act similarly against acidulation.

In Hellriegel's nutrient mixture, nitrogen is in the $Ca(NO_3)_2$ form (physiologically alkaline salt) and acting as a buffer against alkalinization is KH_2PO_4.

In Pryanishnikov's mixture, the buffering effect on acidulation (NH_4NO_3 being a physiologically acidic salt) is produced by dicalcium phosphate ($CaHPO_4 \cdot 2H_2O$). In Belousov's nutrient mixture, the function of buffers is performed by mono- and disubstituted phosphates. This mixture was developed for sugar beet, and its salts include NaCl.

The original Knop's, Hellriegel's, and other mixtures for normal plant nutrition included such nutrients as N, P, K, S, Ca, Mg and Fe. In view of the extraordinary strides made in natural sciences in general and in agricultural chemistry in particular as well as significant advances in nutrient salt and sterile medium (sand, water) purification, the number of nutrients necessary for optimal plant development has increased substantially, and up-to-date formulations must also include such micronutrients as boron, copper, zinc, molybdenum, manganese, cobalt, and the like.

Experiments with sand cultures are established and carried out similarly to those with soil cultures with the difference that nutrients are applied to sand cultures in mixtures including solutions of individual salts or dry insoluble salts.

The sand for such experiments is prepared as follows.

Concentrated hydrochloric acid is poured on sand to dissolve the impurities present in the latter. The acid is then

removed by repeated washing with tap or distilled water
(till the qualitative reaction with $AgNO_3$ for the Cl ion dis-
continues).

A comparison of sterile media indicates that sand is con-
taminated to a greater degree than water. Water provides
for a more even distribution of nutrients whose concentra-
tion is equalized more rapidly as they are being consumed by
plants, however, experiments with water cultures are ex-
tremely labour- and time-consuming, which is why the proce-
dures of such experiments are not as elaborate.

Greenhouse experiments with water culture involve glass
or polyethylene pots with capacities ranging from 3.5
to 5 and more litres.

Three fourths of a pot are filled with distilled water. Then,
according to the experimental procedure, the necessary amount
of a nutrient salt solution is added using a pipette or a
graduated cylinder (each nutrient mixture solution must be
handled with its own pipette or cylinder), the distilled water
is made up to the mark 1 cm below the rim, the contents are
thoroughly stirred, and the pot is stoppered with round
pieces of wood with four to five holes 1.5 to 2 cm in diameter.
The prepared plants are planted into these holes, one hole
in the centre being left to receive the supporting frame and
another one, for insertion of a glass tube through which air
is blown to aerate the roots.

The wooden stopper is fitted tightly into the pot with its
narrower bottom portion, while the upper portion which is
0.5 cm wider than the pot diameter rests upon the pot rim.
Double hoods with a lace in the upper edge are put on the
glass pots. The inner hood made of a black cloth screens the
light off the nutrient solution and roots, while the outer,
white hood protects the pots against overheating. The lace
is then tightened for the hoods to enwrap closely the outer
portion of the wooden stopper.

Before a water culture experiment, seeds are first made to
germinate in troughs with sand (just as in soil culture ex-
periments), then the sprouts are carefully transferred onto
wax-impregnated gauze for further growth, the gauze being
placed on a crystallizer filled with water or a lean nutrient
solution (1/10 of the nutrient mixture). As soon as the roots
reach 5 to 6 cm in length, the plants are removed and the

roots are trimmed for better branching. The plants are then secured in the holes with the aid of cotton wads so that the roots are immersed in the solution.

Plant care in water culture boils down to daily aeration of the nutrient solution.

Systematically, as the solution keeps evaporating in water culture experiments, the distilled water should be made up to the mark and pH of the medium should be regularly checked.

In the course of vegetation, according to the experimental schedule, the nutrient mixture solutions in the pots are changed completely three to four times.

When water culture plants are harvested, the yield of the above-water parts and roots is determined.

8.3 Lysimeter Experiments

Just as field and greenhouse experiments, lysimeter ones belong to biological research and have gained wide recognition in some of the natural sciences.

The lysimeter (from the Greek word "lysos" meaning "dissolution, loosening") is a simple device used for the first time by the English scientist John Dalton at the turn of the 18th and 19th centuries to elucidate the role of atmospheric precipitations in the feeding of groundwater.

The lysimetric method in agricultural chemistry permits determining the composition of filtration water, observing the percolation of precipitation water, monitoring the changes in soil moisture content, establishing (under natural conditions) the transpiration coefficients of individual plants, detecting the changes affecting some soil properties under the effect of fertilizers, and so on.

Lysimeter experiments are carried out in agricultural chemistry primarily to determine losses of the nutrients leached out during infiltration when fertilizers are applied.

A comparison of the content of nutrients and their supply into the soil and their removal by crops from it provides data for drawing up the soil nutrient balance which will form the basis of an appropriate fertilizer system.

These experiments involve several lysimeter designs differ-

ing in the additional devices used for studying the percola-
tion of water and the nutrients dissolved in it.

The installation of lysimeters and their appurtenances
should meet the following requirements:

(1) Provision must be made for observations under condi-
tions as close to the immediate environment as possible. To
this end, lysimeters are dug into the ground, the soil level
in them being the same as outside.

(2) For purposes of comparative studies or experimenta-
tion following a specified procedure, several lysimeters (10
and more) are necessary. To meet this requirement, lysimeters
are usually arranged in groups spaced a certain distance
apart in two rows as a rule.

(3) To collect the water percolating through the soil drain-
age is usually provided, followed by short pipes emerging
into an underground corridor which accommodates special
receivers. The corridor has natural and artificial lighting
to enable round-the-clock observations. The underground cor-
ridor is properly waterproofed to prevent water from seep-
ing into the lysimeters and heat-insulated to avoid sudden
temperature changes (especially in winter).

(4) Depending on the experimental procedure (schedule),
the investigations may be conducted in both fallow lysim-
eters and lysimeters in which various plants are grown.
Sometimes, trees are also planted in lysimeters (Williams).
Therefore, the arrangement of lysimeters must satisfy the
condition ensuring normal plant development, for example,
adequate lighting, protection of crops against damage inflict-
ed by animals and birds, and so on. To this end, lysime-
ters are covered with meshes similar to those used on green-
houses.

(5) Since measuring the amount of atmospheric precipita-
tions is rather important in lysimeter experiments, a rain
gauge must be installed near the lysimeter.

(6) Lysimeters are located near the laboratory to avoid
transportation of large quantities of water and to carry out
observations and investigations at any hour of the day in
any weather.

Depending on the way in which lysimeters are filled with
soil, they are classified in two categories:

(1) Lysimeters with naturally structured soil.

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(2) Lysimeters with filled soil, in which the natural soil structure is disturbed, but sifted soil is placed in lysimeters with the natural sequence of its horizons being preserved, then compacted, as a rule, to its natural volume.

In terms of design, the classification is as follows:

(1) Concrete or brick lysimeters,

(2) Metal lysimeters,

(3) Lysimetric (Ebermeyer) funnels.

In recent years, lysimeters made of plastic films have been coming into use.

Concrete or brick lysimeters are intended for prolonged use, have a surface area of 1.2 and even 4 square metres, and are suitable for experiments only with filled soil. These lysimeters are used by many research institutions in different countries for stationary perennial experiments.

At the Timiryazev Agricultural Academy in Moscow, concrete lysimeters designed by Williams and built in 1900 had been in use till the early thirties. A total of ten lysimeters had been installed in two rows with five lysimeters in each. Their volume was 4 m³ (2 × 2 m area by 1 m depth). The drainage system (on the lysimeter bottom) was of short glass tubes rather than sand and gravel.

Metal lysimeters vary widely in design, configuration, and volume. They can accommodate both naturally structured and filled soil.

Metal lysimeters are made of galvanized steel sheets, the inner surface being sometimes coated with a bituminous compound. Just as in concrete lysimeters, sand and gravel drainage is provided on the bottom.

In experiments with filled soil, use is often made of cylindrical or cubic lysimeters which are filled with soil and either dug directly into the ground or inserted into another metal receptacle of a larger size. The latter is buried in the ground and serves, firstly, to reinforce the lysimeter walls and, secondly, to permit easy withdrawal of the lysimeter for weighing. In some cases, metal lysimeters are mounted on carriages travelling in a trench. The carriage with a lysimeter is driven onto scales in the middle of the trench for weighing.

Metal lysimeters with naturally structured soil are usually cylindrical in shape with sharpened edges on the bottom to be more easily driven into the ground to receive the soil.

After such a lysimeter has been filled with naturally structured soil, a funnel-shaped bottom filled with a drainage material is tightly secured to it, and the whole is permanently installed in place.

All metal lysimeters have bottoms with a hole communicating via piping with a filtrate receiver. Such lysimeters can be kept fallow or accommodate various plants.

Lysimetric funnels are used for experiments with naturally structured soils because it is commonly believed that driving metal lysimeters into the ground causes disturbances of the natural structure, no matter how minor they may be. Therefore, to simulate the natural conditions as accurately as possible, research workers get rid of the side walls of a conventional lysimeter and place funnels at different depths to receive the percolating water.

Lysimetric funnels are made of galvanized iron, vinyl plastics, plexiglas, or other materials. They are filled with a drainage material and installed as follows.

Recesses are made at a given depth in a vertical wall of a trench, and the funnels are driven with their sharp edges into the ceiling of each recess. (Funnels are usually 25 to 50 cm in diameter and 5 cm deep). The funnel ends are connected by pipes with receivers. The funnels are spaced 30 to 100 cm apart, all voids in the recesses are filled with earth once the funnels have been installed, the trench is backfilled, and a covered manhole is provided for access to the receivers.

Lysimetric funnels are believed to offer certain advantages over other types of lysimeters (Bobritskaya *et al.*), primarily because observations are possible in a soil whose natural structure has been preserved.

However, when lysimetric funnels are used, water may flow into them from the sides or out into the adjacent plots. Therefore, in experiments with lysimetric funnels, plots with different fertilizers must be separated by defensive strips as in field experiments.

Experiments have shown that the water regime in lysimeters differs from that in natural soils. For instance, walled lysimeters receive 20 to 25 per cent more precipitations than soils under natural conditions when the water flows

down slopes, substantial differences being also observed in the dynamics of various forms of soil moisture.

The drainage system in lysimeters creates an air cushion which prevents free gravity flow of the water. This is why excess moisture, as compared to a similar layer of natural soil, is observed in lysimeters. The water percolation rate depends on the lysimeter depth, and in deeper lysimeters it is relatively higher than in shallow ones. Conversely, evaporation is more intensive from the surface of shallow lysimeters, as opposed to deep ones, and differs substantially from that from natural soils.

Having analyzed the results of numerous experiments, Golubev and Yudin point out that the amount of percolating water also depends on the following factors:

(1) The way in which a lysimeter is filled (percolation proceeds at a faster rate in soils that have retained their natural structure, as opposed to filled soil which is compacted);

(2) Soil properties (the finer the soil particles, the less intensive the percolation);

(3) Season (in spring and in autumn, the percolation rate is higher than in winter and in summer);

(4) Amount of precipitations and their distribution in time (a lot of precipitation within a shorter period of time is responsible for a higher percolation rate);

(5) Air and soil temperature (the higher the temperature, the more intensive the evaporation and the lower the percolation rate);

(6) Presence or absence of plants (in lysimeters with plants, the percolation rate is lower than in fallow lysimeters because of the transpiration of water by plants).

Thus, the water regime of lysimeters differs markedly from that of natural soils, and the results of lysimeter experiments differ from those of field ones. However, experimentation in lysimeters provides reliable and comparable results.

Lysimeter experiments are widely used in agricultural chemistry to determine the rate of nutrient leaching from the soil, which is directly associated with percolation and is largely dependent on the above factors in view of the fact that water also leaches out soluble nutrients from the root zone of the soil.

However, experiments indicate that the amount of loss

is more heavily dependent on the content of mobile nitrogen forms and, to a lesser extent, on the amount of annual precipitations giving rise to percolation. The mobility of nitrogen is determined by soil texture: at the same amount of percolated water, 7.4 times more nitrogen is leached out of sandy soil as compared to loam. Phosphorus losses due to leaching are insignificant.

Golubev, who has summarized the results of many years of experimentation by different workers, involving untreated soils in lysimeters 1 m deep, reports the following leaching losses (kg/ha): nitrogen, 12.8, phosphorus, 1.2, potassium, 27.4, sulphur, 51.4, calcium, 46.8, magnesium, 32, and silica, 46.8.

According to Bobritskaya, maximal nitrogen losses due to leaching occur in fallow soil, and its volatilization usually involves lower oxide and molecular forms which constitute 78 to 98 per cent of the total loss.

Thus, in spite of some departure from natural conditions, lysimeter experiments nevertheless permit studying the migration of nutrients and moisture in natural soils, give an insight into the nutrient regime of the soil, and make it possible to directly estimate one of the nutrient balance components on the debit side.

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